Three Essays on Money and Liquidity

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Section I

Introduction

Money and liquidity play an important role in the financial system. For banks, the ability to convert assets (e.g. securities) into central bank money, often called liquidity, is of inherent importance and has received even more policy attendance since the financial crisis. On the one hand, banks can use repurchase (repo) markets to exchange securities as collateral to borrow liquidity on a temporary basis. On the other hand, banks might also store securities as a liquidity buffer which can be converted into liquidity when needed.

This thesis focuses on banks' ability to generate liquidity. In particular, in the following essays I develop an algorithm to analyze the re-use of collateral in repo markets, examine liquidity (in the financial economics sense of the word) in the Swiss franc repo market, and illustrate how the recently introduced "Liquidity Coverage Ratio" (LCR) – a new regulation proposed by the Basel Committee on Banking Supervision which requires banks to hold sufficient liquidity buffers to withstand severe short-term liquidity stress – affects financial markets.

The first essay (see Appendix I), co-authored with Basil Guggenheim and Silvio Schumacher and published in the Journal of Money Credit and Banking (Vol. 48, Issue 6, 2016), examines the re-use of collateral in the repo market. The essay introduces a methodology to estimate the re-use of collateral based on actual transaction data. With a comprehensive dataset from the Swiss franc repo market we are able to provide the first systematic study on the re-use of collateral. We find that re-using collateral was most popular prior to the financial crisis when roughly 10% of the outstanding interbank volume was secured with re-used collateral. Furthermore, we show that the re-use of collateral increases with the scarcity of collateral. By giving an estimate of the collateral re-use and explaining its drivers, the essay contributes to the on-going debate on collateral availability.

The second essay (see Appendix II), written together with Benjamin Müller and Luzian Steiner and published in the Journal of Banking & Finance (Vol. 75, 2017), addresses the question what the added value of a security is, which qualifies as a "high-quality liquid asset" (HQLA) under the LCR. In this essay, we quantify the added value and, as suggested by Stein (2013), call it HQLA premium. To do so, we exploit the introduction of the LCR in Switzerland as a unique quasi-natural experiment and we find evidence for the existence of an HQLA premium in the order of 4 basis points. Guided by theoretical considerations, we claim that the HQLA premium is state dependent and argue that our estimate is a lower bound measure. Furthermore, we discuss the implications of an economically significant HQLA premium. Thereby, we contribute to a better understanding of the LCR and its implications for financial markets.

The third essay (see Section II) examines liquidity in the Swiss franc repo market and assesses its determinants using a proprietary dataset ranging from 2006 to 2016. I find that repo market liquidity has a distinct intraday pattern, with low liquidity in early and late trading hours. Moreover, repo market liquidity is negatively affected by stress in the global financial system and the end of the minimum reserve requirement period if central bank reserves are scarce. Furthermore, I show that with excess central bank reserves in the financial system, quoted volumes in the interbank market get imbalanced towards more cash provider relative to cash taker quotes and the trading volume declines. By estimating liquidity in an interbank repo market and explaining its drivers, this essay contributes to the ongoing debate on repo market functioning.

The three essays were written with the support of the Swiss National Bank. However, the content of the publication is the sole responsibility of the author and does not necessarily reflect the views of the Swiss National Bank.

Section II

Liquidity in the Repo Market*

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Abstract

This paper examines liquidity in the Swiss franc repurchase (repo) market and assesses its determinants using a proprietary dataset ranging from 2006 to 2016. I find that repo market liquidity has a distinct intraday pattern, with low liquidity in early and late trading hours. Moreover, repo market liquidity is negatively affected by stress in the global financial system and the end of the minimum reserve requirement period if central bank reserves are scarce. Furthermore, I show that with excess central bank reserves in the financial system, quoted volumes in the interbank market get imbalanced towards more cash provider relative to cash taker quotes and the trading volume declines. By estimating liquidity in an interbank repo market and explaining its drivers, this paper contributes to the ongoing debate on repo market functioning.

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1 Introduction

Banks commonly use repurchase (repo) markets to smooth liquidity shocks. Although these markets are of great importance for the financial system (Fecht, Nyborg and Rocholl, 2011), little is known about the underlying liquidity (in the financial economics sense of the word) of those markets. As in the repo market, central bank reserves (reserves), often called liquidity, is exchanged against collateral, the repo market can be considered liquid if a bank can borrow or lend reserves at any time, at a low cost, and without moving interest rates (see, for instance, Black (1971) and Kyle (1985)).

This paper contributes to the economic literature by describing liquidity and identifying its key determinants in the Swiss franc (CHF) overnight repo market where reserves are exchanged against collateral, which is also used by the Swiss National Bank (SNB) in its monetary policy operations.[1] The analysis I conduct is unique, as it is based on the entire quote book as well as all trades from the prevailing electronic trading platform for CHF repo transactions ranging from 2006 to 2016. Consequently, it allows an intraday analysis of market liquidity prior to, during, and after the financial crisis as well as in a positive and a negative interest rate environment. Moreover, by analyzing how reserves exceeding banks' minimum reserve requirements (excess reserves) affect liquidity in the interbank market, the paper contributes to a better understanding of how accommodative monetary policy affects interbank markets.

I capture liquidity in the CHF repo market by studying standard measures of transaction costs and price impacts. On the one hand, transaction costs are measured by the quoted bid-offer spread as well as the effective spread which is based on actual transactions. On the other hand, price impacts are approximated by changes in quoted mid-rates following a repo trade and the volatility of repo trade rates. Furthermore, to describe the more general market activity, I calculate the size of the cash taker quote volume, the cash provider quoted volume, and the trade volume. The key stylized facts of repo market liquidity can be summarized as follows. First, I show that repo market liquidity has a distinct intraday pattern, with low liquidity in the early and late trading hours. Second, the measures reveal that at the peak of the financial crisis, liquidity in the CHF repo market was subdued. For example, in October 2008 the bid-offer spread reached levels of up to 100 basis points (bps; about 50% of the interest rate level at that time) compared to an average bid-offer spread of about 7 bps prior to the financial crisis. Third, with the extraordinary liquidity injections by the SNB in the months after of the financial crisis, liquidity indicators returned back to pre-crisis levels relatively quickly. Fourth, with excess reserves in the financial system after the financial crisis, the structure of the interbank market changed considerably. Quoted volumes became imbalanced towards more cash providers and

[1] Studying the liquidity characteristics of repo markets is of particular interest in the overnight maturity, as banks satisfy their short-run liquidity needs predominantly in this maturity. Banks with excess reserves (e.g., from client inflows) typically lend, whereas banks with a need for liquidity (e.g., from client outflows) typically borrow reserves.

the trade volume declined substantially. This is due to the fact, that with excess reserves, banks have no or little need to trade reserves in the interbank market anymore. Along with this, fewer market liquidity indicators can be calculated as only few banks act as cash takers in the repo market.

To identify the key determinants of market liquidity, I run different regression specifications using market liquidity indicators on a daily and an intraday frequency. The regression results indicate that market liquidity indicators are affected by the SNB's monetary policy framework. In this regard, I find that market liquidity is reduced at the end of the minimum reserve requirement period before the financial crisis, i.e. in the period where reserves are scarce. Moreover, when interest rates trade close to the SNB's deposit rate, price impact indicators are low as there is little uncertainty about overnight repo rates. This is due to the fact, that all market participants in the CHF repo market have a sight deposit account at the SNB and that depositing excess reserves at the central bank is an available outside option for all banks. Additionally, a negative risk sentiment in the global financial system affects liquidity in the CHF repo market negatively. If market participants are more risk-averse, they place fewer and more conservative quotes in the interbank market, and market liquidity declines.

Monitoring and understanding the determinants of repo market liquidity is important for central banks and regulators for the following reasons. First, decreasing liquidity in repo markets deteriorates banks' funding conditions. This, in turn may trigger illiquidity in other financial market segments (see Nyborg and Östberg (2014) and Rupprecht, Ranaldo and Wrampelmeyer (2016)) and ultimately affects the real economy. Consequently, liquidity in repo markets signals vulnerabilities in the financial system, and liquidity measures can be used as indicators for financial stability risks (see Nyborg (2008) and Committee on the Global Financial System (2017)).[2] Second, repo rates are of importance for the transmission of monetary policy and the determination of the yield curve. When liquidity in repo markets evaporates, banks' insurance against sudden liquidity shocks becomes costlier and interbank repo rates increase ("liquidity premium"; see Amihud and Mendelson (1986)). Consequently, the liquidity premium in repo markets affects the transmission of monetary policy and central banks may need to take this premium into account to establish the desired monetary conditions. Third, my analysis shows that for the definition and the design of robust benchmark interest rates, regulators need to consider that trading activity is subdued and cash taker quotes are rather rare in an environment with excess reserves. Thus, it is important to consider all available quoted repo rates and trades for the calculation of reliable benchmarks and not to apply quote and trade filters that are too strict.

The remainder of this paper is structured as follows. Section 2 gives an overview on the literature while Section 3 describes the institutional framework of the CHF repo market. Section 4 defines the liquidity measures and provides descriptive statistics thereof. The determinants of

[2] Deteriorating repo market liquidity is considered a financial stability risk by the Bank of England (2015).

market liquidity are empirically analyzed in Section 5. Finally, Section 6 concludes.

2 Literature

This paper can be incorporated into the literature that analyzes liquidity in money markets, the more general literature on the role and the importance of money markets, and the theoretical and empirical literature on liquidity in equity, fixed income, and foreign exchange markets.

2.1 Market liquidity in money markets

Repo markets are used by banks to exchange liquidity on a secured basis and are an important segment of money markets.[3] Though repo markets, of great importance for the financial system and their analysis is of first order relevance (Fecht, Nyborg and Rocholl, 2011), up to now relatively little is known about the underlying liquidity in those markets.

In particular, to the best of my knowledge, repo market liquidity has been analyzed only by one paper, and few studies exist on liquidity in unsecured markets. Dunne, Fleming and Zholos (2011) provide an in-depth description of different market liquidity indicators for the euro (EUR) repo market between 2006 and 2009 using trade and quote data from the BrokerTec trading platform. The authors illustrate that bid-offer spreads increased dramatically with the outbreak of the financial crisis, but returned to pre-crisis levels relatively shortly afterwards. Moreover, Dunne, Fleming and Zholos (2011) examine how changes in European Central Bank (ECB) open market operations during the financial crisis affected the efficiency and reliability of the repo market (measured by market liquidity indicators) as secondary market for reserves.[4] Most importantly, they find that the conditions in the interbank market mirror the outcomes in ECB operations and liquidity in the interbank market improves after more favorable ECB auction outcomes.

Based on trade and quote data from the e-Mid trading platform, Brunetti, Di Filippo and Harris (2011), Beaupain and Durré (2013), and Beaupain and Durré (2016) analyze liquidity in the unsecured market for EUR liquidity. Brunetti, Di Filippo and Harris (2011) illustrate that the main refinancing operations by the ECB positively affected liquidity prior to the financial crisis but negatively affected liquidity during the financial crisis. The authors conclude that these operations failed to reduce asymmetric information problems prevalent in the unsecured money market and were hence unable to improve liquidity. Moreover, Brunetti, Di Filippo and Harris (2011) show that the extraordinary refinancing operations of the ECB increased uncertainty in

[3]See, for instance, Euro money market survey, September 2015.

[4]Central bank operations can be understood as the primary market, while the interbank market as the secondary market for reserves (Bindseil, Nyborg and Strebulaev, 2009). In this regard, two different views exist. On the one hand, there is a strain of literature building on Goodfriend and King (1988), which argues that interbank markets allocate liquidity efficiently. On the other hand, there is the literature building on Bhattacharya and Gale (1987), which argues that market liquidity in interbank markets might not be resilient during times of crisis; thus the allocation of reserves is prone to be inadequate.

financial markets and reduced the supply of reserves in the interbank market. Beaupain and Durré (2013) analyze liquidity in the same market but focus on the general determinants of market liquidity. They find that market liquidity depends on the amount of reserves in the financial system, the general market activity, and on the so-called operational framework of the ECB. In particular, they illustrate that the adjustment of the ECB's operational framework in 2004 significantly improved market liquidity.[5] More recently, Beaupain and Durré (2016) assess the impact of the ECB's fixed-rate full-allotment policy on the unsecured interbank market and find that in this period liquidity in the money market depends on the level of excess reserves.

2.2 Role of money markets

With regard to the more general literature on money markets, most relevant for my paper is the analysis by Bindseil, Nyborg and Strebulaev (2009), where the structure and imperfections of the market for reserves in the euro area are studied on the basis of banks' bidding behavior in ECB repo auctions. On the one hand, the authors show that banks' bidding behavior is affected by the allocation of reserves, i.e., they find evidence that the allocation of reserves in repo auctions matters. Thereby, they also show that liquidity in the interbank market is not perfect. On the other hand, Bindseil, Nyborg and Strebulaev (2009) find that private information about future short-term rates does not play a central role in banks' bidding behavior and infer that the market is informationally efficient. Following this argument, Fecht, Nyborg and Rocholl (2011) analyze the determinants of interest rates that banks pay in central bank repo operations using bank characteristics and market conditions as explanatory variables. They find that the price for liquidity is higher if the distribution of reserves is more imbalanced and thereby confirm that the amount and the allocation of reserves matters. In addition, Nyborg and Östberg (2014) provide empirical evidence that the demand for liquidity generally affects financial markets. When liquidity in the interbank market declines, market participants sell relatively more liquid assets, which the authors term "liquidity pull-back". Consequently, their finding highlights the importance of understanding the determinants of liquidity in the repo market.

Moreover, my analysis is also related to empirical papers, which describe the behavior of repo markets during the financial crisis. For the bilateral repo market in the US, Gorton and Metrick (2012) document that haircuts increased dramatically and repo volumes declined during the recent financial crisis, i.e. there was a "run on repo". Copeland, Martin and Walker (2014) and Krishnamurthy, Nagel and Orlov (2014) analyze the US tri-party repo market and show that repo volumes in this market also declined; however, haircuts remained stable as relatively high quality collateral was used. Thus, the authors provide evidence that no system-wide run on repo occurred. Similarly, Mancini, Ranaldo and Wrampelmeyer (2016) showed that the central counterparty European repo market serves as a shock-absorber and ensures a resilient money

[5] As of May 2004, the ECB aligned the reserve maintenance period to the Governing Council meetings and reduced the maturity of the main refinancing operations from two weeks to one week.

market even during periods of stress.

2.3 Market liquidity theory and empiricism

This paper is also related to the theoretical and empirical literature on liquidity in equity, fixed income and foreign exchange markets. Theoretical studies in the tradition of Demsetz (1968) associate market illiquidity with the asynchronous arrival of buyers and sellers with immediate trading interest. In those frameworks, transaction costs represent the price for providing immediacy and is determined by the costs of market makers, which quote bid and offer prices at the same time, as well as the degree of competition between market makers (see, for example, Foucault, Pagano and Röell (2013) and O'hara (1995)). In particular, the costs of market making is analyzed in detail and depends on the costs of holding inventories (see, for example, Garman (1976) and Stoll (1978)) as well as private information about the true value of the assets (see, for example, Copeland and Galai (1983), Amihud and Mendelson (1980), and Kyle (1985)). More recently, Duffie, Gârleanu and Pedersen (2005) study how imperfect competition among market makers affects market liquidity. In their framework, market illiquidity is the margin, which market makers are able to extract from their clients and thus reflects the degree of imperfect competition. Apart from these theoretical papers, liquidity has been extensively analyzed in equity markets (see, for example, Chordia, Roll and Subrahmanyam (2000), Chordia, Roll and Subrahmanyam (2001), Hasbrouck and Seppi (2001), Huberman and Halka (2001), and Chordia, Sarkar and Subrahmanyam (2005)). In fixed income markets, for instance, Fleming and Sarkar (1999), and Fleming (2003) describe liquidity in the U.S. treasury market, whereas Mancini, Ranaldo and Wrampelmeyer (2012) and Karnaukh, Ranaldo and Söderlind (2015) provide empirical evidence on liquidity in major foreign exchange markets.

3 Institutional background

Next to the institutional setup of the interbank market, monetary policy implementation by the SNB may crucially influence liquidity in the repo market. Hence, the following subsections discuss the institutional setup of the interbank market and SNB's monetary policy framework in detail.

3.1 Characteristics of the CHF repo market

Trading in the CHF repo market takes predominantly place on an electronic trading platform that was launched in 1999 (Kraenzlin and von Scarpatetti, 2011) and was operated by Eurex Repo Ltd. up to 2 May 2014 and by SIX Repo Ltd. afterwards.[6] The trading platform is set up

[6]Note that all technical functionalities, such as the trading interface, were identical on the two trading platforms. As of 2 May 2014, the vast majority of market participants had access to the new trading environment and trades are conducted predominantly on the SIX repo trading platform.

as a non-anonymous market with bilateral trade relationships. Quote-based trading is predominant[7] for the overnight maturity and works in a fairly simple way: market participants who enter quotes (similar to "limit orders" in equity markets) must specify the following information: maturity, bid/offer indicator, cash amount, repo rate, and collateral basket.[8] To execute a trade, market participants can hit a quote via a click.

Pre- and post-trade transparency is high in the CHF repo market. Quotes are collected in a so-called quote book (similar to a "limit order book" in equity markets), which is displayed for all market participants in the market overview section of the trading platform. The quote book shows all bid and offer quotes ordered by maturity, bid/offer indicator, and repo rate. Thus, market participants can immediately identify the best quoted repo rates, the bid-offer spread, and the quoted volumes for a given maturity. Moreover, the terms of trade (repo rate, volume, maturity, and collateral basket) of all concluded repo transactions are instantaneously visible to all market participants in a public trade list. Therefore, all market participants have the same information set, and current market conditions are common knowledge at all times.

As of 2015, the trading platform has about 150 eligible market participants. Market participants are predominantly banks as well as a few insurance companies domiciled in Switzerland (two-thirds) and banks domiciled abroad (one-third).[9] All market participants have a sight deposit account at the SNB, and most market participants are an eligible counterparty of the SNB in its open market operations.

3.2 Collateral standards[10]

The CHF repo market is highly standardized. Almost all repo transactions (i.e., more than 99%) are traded against a collateral basket and approximately 95% of the outstanding volume is secured with the collateral basket used, defined and maintained by the SNB, the so-called SNB GC basket. Compared to other central banks, the SNB has a relatively strict collateral framework with regard to the collateral quality but a relatively liberal framework concerning the eligible currencies.[11] SNB eligible securities can be denominated in CHF as well as EUR, US Dollars, Pound Sterling, Danish Krone, Swedish Krona and Norwegian Krone. All eligible securities must be marketable and traded on a recognized stock exchange or a representative market that publishes price data on a regular basis. Moreover, the volume at issuance must at least be CHF 1 billion (bn) for securities denominated in foreign currencies and CHF 100 million (mn) for securities denominated in CHF. To ensure collateral quality, SNB eligible securities must

[7]The share of quoted-based trades is more than 90% in the overnight maturity.

[8]Note that further specifications, such as substitutions and early termination rights, as well as collateral haircuts, are predefined by default but adjustable by market participants.

[9]Since 2006, the number of market participants increased from about 125 to 150. This was mainly due to new participants after the financial crisis, when foreign banks in particular requested access to the market.

[10]This subsection is based on the SNB's instruction sheet on collateral eligible for SNB repos (see Swiss National Bank (2016), Swiss National Bank (2004), and Fuhrer, Müller and Steiner (2017)).

[11]For a detailed discussion of the importance and the role of central banks' collateral framework see Nyborg (2016), Nyborg (2017), and Fecht, Nyborg, Rocholl and Woschitz (2016).

have a minimum long-term rating of AA- (where the second-best rating of Standard & Poor's, Moody's and Fitch is decisive). The list of SNB eligible securities is subject to daily modifications due to new issues, redemptions, and exclusions. At the end of 2015, the total volume of collateral eligible for SNB repos amounted to roughly CHF 9,200 bn. Overall, the relatively high quality of the securities accepted in the SNB GC basket ensures that interbank transactions can be considered as nearly free of counterparty risks (Kraenzlin, 2008). In interbank repo transactions against the SNB GC basket no haircuts are applied (as defined in the collateral framework of the SNB), the right for collateral substitution is usually not granted, and re-use of collateral is possible (Fuhrer, Guggenheim and Schumacher, 2016).

3.3 Infrastructure

The trading platform is directly linked to the central securities depository (called SECOM) and the real-time gross settlement payment system (called Swiss Interbank Clearing, SIC).[12] Together, these systems constitute an infrastructure that allows for the complete electronic integration of trading, clearing and settlement, the so-called Swiss value chain. The Swiss Master Agreement for repo transactions and the Global Master Repurchase Agreement (GMRA) with Swiss Annex form the legal basis for any repo transaction in the Swiss repo market (SIX Repo, 2016). Interbank repo transactions are settled in central bank money, the settlement is done as delivery versus payment, and no daily "unwinding" of positions occurs (which has proven to be problematic in the United States (Copeland, Martin and Walker, 2010)). To obtain access to the CHF repo system, market participants must have a sight deposit account at the SNB (Swiss National Bank, 2010). In particular, the SNB requires candidates for a sight deposit account to make a "significant contribution to the fulfilment of the SNB's mandate and do not bring with them any major risks" (Swiss National Bank (2010). Therefore, the access policy of the SNB determines the number of market participants in the CHF repo system (Kraenzlin and Nellen, 2015) and ensures that only market participants with a sufficient credit rating are eligible.

3.4 Monetary policy environment

The SNB's operational framework for the implementation of monetary policy can be differentiated into three periods: a liquidity-neutral period lasting from the beginning of the sample period until 14 September 2008, an excess liquidity period lasting from 15 September 2008 to 21 January 2015, and a negative interest rate period with excess reserves from 22 January 2015 onwards (as illustrated in Figure 1).

Liquidity-neutral period: Prior to the financial crisis, the SNB implemented monetary policy in structural liquidity deficit (Berentsen, Kraenzlin and Müller, 2015). In this environment, the

[12]SECOM also serves as tri-party agent, which takes care of the settlement, ongoing valuation of the collateral, and the initiation of margin calls.

SNB provided the financial system with enough reserves so that banks could fulfill the minimum reserve requirements in aggregate, i.e., a so-called liquidity-neutral policy (see definition in Bindseil, Nyborg and Strebulaev (2002)). By requiring banks to hold minimum reserves, the SNB ensures banks' demand for reserves and aims to stabilize money market rates. Minimum reserves must be held at an average level over the reporting period, which lasts from the 20th of the current month until the 19th of the following month.[13] The aggregate minimum reserve requirement of the banking system was about CHF 8 bn in 2006 and increased slightly to roughly CHF 11 bn in 2015 (see Figure 6 Panel B).

The provision of reserves in the liquidity-neutral period was predominantly done via daily open market operations (i.e. fixed-rate repo auctions), normally with a one-week maturity, and the amount of reserves in the financial system was kept constant (see Figure 6 Panel B).[14] In this period, the SNB did not remunerate reserves (i.e., the deposit rate was zero) and the pricing of the standing facility lending rate was calculated as the average overnight rate (midday fixing) plus 200 bps. Thus, the SNB operated a so-called corridor system and steered money market interest rates via the conditions offered in the open market operations (see, e.g. Jordan and Kugler (2004) and Berentsen, Marchesiani and Waller (2014)).

Excess liquidity period: Following the Lehman Brothers collapse on 15 September 2008, the SNB started to provide the banking system with additional reserves via exceptional liquidity-providing operations (see Figure 2). Specifically, the SNB increased the allotment volume in regular repo auctions, conducted longer-term repo operations, and even went over (from 29 October 2008 onwards) to fully allot all bids submitted by banks in daily fixed-rate repo auctions (i.e., fixed-rate full allotment policy). Moreover, the SNB cooperated with foreign central banks to indirectly distribute CHF liquidity to foreign banks with CHF funding needs.[15] Additionally, the SNB started to purchase foreign currencies to combat deflationary risks up from March 2009 (see Figure 2, Swiss National Bank (2009a)). The FX purchases led to a structural liquidity surplus with reserves in the financial system exceeding the minimum requirement by a multiple (factor 27 as of January 2015). For this reason, after the financial crisis, minimum reserve requirements are no longer binding for the banking system and the SNB stopped liquidity-providing repo auctions on 12 May 2010 (see Figure 6 Panel B).[16] In the excess liquidity period, the SNB did not remunerate reserves (i.e., the deposit rate was zero), the add-on for the pricing

[13]Minimum reserve requirements are calculated as a fraction of banks' short-term liabilities (see National Bank Act, arts. 17 et seq. and National Bank Ordinance, arts. 12 et seq.). Banks can use CHF coins, banknotes and reserves to fulfill minimum reserves requirements.

[14]For more details on SNB repo auctions, see Kraenzlin and Schlegel (2012).

[15]For that purpose, the SNB provided foreign central banks CHF liquidity via EURCHF-Swaps (for more details, see Swiss National Bank (2008), Swiss National Bank (2009b), and Auer and Kraenzlin (2011)).

[16]Currently, the SNB is only operating its so-called "liquidity-shortage financing facility", which has hardly been used in recent years (see SNB accountability reports). Between 5 July 2010 and 2 August 2011, the SNB absorbed excess liquidity from the financial system via the issuance of own debt register claims and liquidity-absorbing repo auctions while from 24 August 2011 to 24 May 2012, the SNB provided the interbank market reserves at a negative rate by placing repo quotes in the interbank market.

of the standing facility lending rate was reduced from 200 to 50 bps as of January 2009 and interbank rates traded closely to the SNB's deposit rate. Consequently, the SNB operated effectively a floor system of monetary policy implementation.

Negative interest rate period: In December 2014 the SNB announced a tiered remuneration system for reserves with negative interest rates of -0.25%, effective as of 22 January 2015 (Swiss National Bank, 2014). On the 15 January 2015, the SNB discontinued the EURCHF minimum exchange rate and at the same time announced to lower negative interest rates by 0.5 percentage points to -0.75%, effective as of 22 January 2015 (Swiss National Bank, 2015). In the tiered remuneration system, reserve holdings that exceed an individually defined threshold are remunerated at -0.75%, while reserves below this threshold are remunerated at 0%. The individually defined thresholds correspond to a multiple of a banks' minimum reserve requirement (currently, factor 20) or a fixed exemption threshold of at least CHF 10 mn for banks without minimum reserve requirement. With the tiered remuneration system, only banks that hold reserves exceeding the exemption threshold are affected by negative interest rates. In the interbank market, the introduction of the tiered remuneration system with negative interest rates created a new trading motivation. Banks holding fewer reserves than their exemption threshold are willing to borrow reserves at a negative rate and deposit it at the SNB at an interest rate of 0%, whereas banks that hold reserves exceeding their exemption threshold are willing to lend reserves at a negative rates as long as it is higher than the negative deposit rate of the SNB which is currently -0.75% (see, e.g. Moser (2016) and Bech and Malkhozov (2016)).

3.5 SARON

Overnight repo trades and quotes are used for the calculation of SARON, i.e. the secured CHF money market reference rate. The reference rate has been developed by the SNB in cooperation with SIX Swiss Exchange Ltd in 2009. SARON can be used as a benchmark interest rate by financial market participants for a variety of purposes (SIX Swiss Exchange, 2016). For example, SARON is planned to replace the TOIS fixing (panel based reference rate for unsecured tomorrow next liquidity) as a benchmark interest rate in CHF overnight index swaps (National Working Group on CHF Reference Interest Rates, 2017).

For the calculation of SARON a trade and quote filter is used which intends to limit the possibilities for manipulations (SIX Swiss Exchange, 2016). For example, the filter considers quoted volumes only if the bid-offer spread is not wider than 6 bps at a specific point in time (SIX Swiss Exchange, 2012). To ensure the continuous calculation of SARON also in periods of subdued trading and quoting activity, five major market participants have signed a Memorandum of Understanding (MoU) for active quoting in October 2013, which encourages market participants to place cash provider and cash taker quotes with a bid-offer spread not exceeding 5 bps. Thus, liquidity in the CHF repo market may also be affected by market participants' efforts to strengthen the continuous calculation of SARON.

4 Measuring liquidity

This section describes measures of liquidity in the CHF repo market. First, the dataset used is described, followed by the definition of the market liquidity indicators used. Afterwards, stylized facts about liquidity is provided.

4.1 Dataset

The proprietary dataset used in this paper includes all quotes and trades from the CHF overnight repo market against the SNB GC basket. The sample covers the period from 3 April 2006 to 26 February 2016, which spans ten years with 2,496 trading days, over 120 minimum reserve requirement periods. Detailed information about the 83,198 trades (day, time, repo rate, and volume) as well as the 262,247 quote entries (day, start-time, end-time, quote type, repo rate, volume, and buy/sell indicator) is available.[17]

4.2 Definition of indicators

To identify liquidity in the CHF repo market, I use standard measures of market liquidity, capturing transaction costs and price impacts. Transaction cost indicators are the quoted bid-offer spread as well as the effective spread which is based on actual trades. If spreads are low, executing a trade is associated with low costs and the market can be considered as liquid. Price impact indicators are the volatility of repo trade rates and the change in repo mid-rates following a repo trade. Price impact measures describe a market's ability to absorb "large" transactions without affecting repo rates. If trades have no or little impact on subsequent repo mid-rates as well as trade rates, market liquidity is considered high. Furthermore, to describe the more general market activity, I calculate the size of the cash taker quote volume, the cash provider quoted volume, and the trade volume.[18] The following paragraphs define the measures in detail and rely on Goyenko, Holden and Trzcinka (2009).

Transaction costs: The simplest form of a transaction cost indicator is the quoted bid-offer spread (BOS_t). The bid-offer spread measures the distance between the best quoted offer rate (p_t^{bo}) and the best quoted bid rate (p_t^{bb}) at time t.

$$BOS_t = p_t^{bo} - p_t^{bb} \tag{1}$$

[17]Extreme outliers are removed from the dataset if the volume is $\geq$ CHF 10 bn or the interest rate is $\geq$ 10%. The volume condition identifies 22 and the interest rate condition 4 erroneous quotes and zero erroneous trades.

[18]It should be noted that measures of trade and quote volumes are not used as market liquidity indicators since their relationship with market liquidity is ambiguous. See, for example, Foucault, Pagano and Röell (2013) and Mancini, Ranaldo and Wrampelmeyer (2012).

As trades are not always executed at the best quoted repo rates, the bid-offer spread might over- or underestimate real transaction costs.[19] The effective spread (EFS_t) controls for this fact, as it measures transaction costs using actual trades. The effective spread is computed as twice the absolute difference between a repo trade rate (p_t^{tr}) and the quoted mid-rate (p_t^m) prevailing at the time of the trade (Goyenko, Holden and Trzcinka, 2009). Thus, it is twice the difference between the effective execution rate and the ideal mid-rate.

$$EFS_t = 2 \cdot \mid p_t^{tr} - p_t^m \mid \tag{2}$$

Price impact: To approximate the price impact of a repo trade, I calculate the 5-minute ($5'$) price impact (PIM_t) for every repo trade. The price impact is calculated as the absolute difference between the quoted mid-rate (p_t^m) prevailing at the time of the trade (t) and the quoted mid-rate ($p_{t+5'}^m$) at time $t + 5'$ (Goyenko, Holden and Trzcinka, 2009).

$$PIM_t = \mid p_t^m - p_{t+5'}^m \mid \tag{3}$$

The price impact of repo trades can also be approximated by the realized volatility of repo trade rates (Jankowitsch, Nashikkar and Subrahmanyam (2011) and Chordia, Roll and Subrahmanyam (2000)). If the volatility of repo trade rates (VOL_t) is high, market liquidity tends to be low. Therefore, I calculate the standard deviation (σ) of repo rates $p_{t,i}^{tr}$ for all trades i conducted in the time interval t to $t + \Delta t$.

$$VOL_t = \sqrt{\frac{1}{I} \sum_i^I (p_{t,i}^{tr} - \mu_t)^2} \tag{4}$$

Quote and trade volumes: In addition to the market liquidity indicators described above, I calculate the size of the cash provider quote volume, the cash taker quote volume, and the trade volume. The size of the cash provider quote volume (QCP_t) at time t is the sum of the quote volume ($q_{t,i}^{CP}$) of all available cash provider quotes (i) at time t, while the size of the cash taker quote volume (QCT_t) at time t is the sum of the quote volume ($q_{t,i}^{CT}$) of all available cash taker quotes (i) at time t.

$$QCP_t = \sum_{i=1}^I q_{t,i}^{CP} \tag{5}$$

[19] In the CHF repo market trades may not be executed at the best prices for several reasons. For example, if the quoted volume at the best rate is small (compared to the intended trade volume) banks may hit the second-best quote to execute the total volume at one price with one counterparty. Moreover, as the CHF repo market is set-up as a market with bilateral trade relationships, banks may also deviate from the best quoted rates as they do not have a trade relationship with the corresponding counterparty. Finally, banks may also execute quotes at a better price directly when new quotes are entered.

$$QCT_t = \sum_{i=1}^{I} q_{t,i}^{CT} \tag{6}$$

The trade volume (TRV_t) is defined as the sum of the transaction volume (v_t) conducted within the time interval t to $t + \Delta t$.

$$TRV_t = \sum_{t}^{t+\Delta t} v_t \tag{7}$$

4.3 Sampling frequency

Liquidity in the CHF overnight repo market can be analyzed between the market opening at 7:00 a.m. and the end of business at 3:55 p.m.[20] To assess the optimal sampling frequency for the calculation of the market liquidity indicators, the trading and quoting frequency in the CHF repo market is analyzed and the optimality principles to separate microstructure noise from volatility proposed by Bandi and Russell (2006) are applied.

Table 1 provides descriptive statistics of trade and quote frequencies. On average, a repo trade occurs every 8.5 minutes and quotes remain active for 56 minutes. Moreover, there are on average 34 repo trades per day and 70 repo quotes. Thus, compared to many other markets, the trading and quoting frequency in the CHF repo market is relatively low. This is also indicated by the optimal sampling frequency, which is approximately 55 minutes according to Bandi and Russell (2006). Based on these findings and to have evenly spaced intervals, I compute market liquidity indicators every 53.5 minutes, resulting in 10 observations per business day, starting at 07:53:30 and ending at 15:55:00.[21] To make this more concrete: the quoted bid-offer spread is calculated at these specific points of the day, the effective spread and the price impact measures are calculated for every repo trade and averaged over the time interval (i.e. over the 53.5 minutes), while the volatility of repo trade rates is calculated using all repo trades within this time interval.[22]

4.4 Stylized facts

Table 3 reports descriptive statistics of market liquidity indicators over the total sample period and the three sub-periods, while Figure 3 depicts the development of market liquidity indicators graphically.

[20]The official trading hours for all maturities, except the overnight maturity, are from 7 a.m. to 6 p.m. The cut-off time for overnight transactions is 3:55 p.m., as the end-of-day processing starts at around 4.15 p.m.

[21]Note that in the regression analysis, I also use market liquidity indicators on a daily frequency to control for the fact that during the excess liquidity period the general market activity was subdued.

[22]Note that the quoted bid-offer spread cannot be calculated at the last intraday observation point (i.e. when the market closes) at 15:55:00. Thus, for the bid-offer spread only 9 observations per business day are calculated.

Development of market liquidity: For the overall sample period, the quoted bid-offer spread is 6.8 bps on average. While it is 7.8 bps in the liquidity-neutral period, it is slightly lower in the excess liquidity and the negative interest rate period with an average of 6.8 bps and 4.8 bps, respectively. The effective spread which is based on actual transactions is 6.3 bps for the overall sample period and thus slightly lower than the bid-offer spread. Figure 3 Panel A illustrates that the bid-offer spread and the effective spread behave very similarly for the overall sample period, indicating that repo trades are predominantly executed at the best available quotes. Moreover, the figure shows that at the peak of the financial crisis bid-offers spreads spiked substantially, reaching levels of up to 100 bps; i.e., more than 50% of the interest level at that time. This spike was temporary, however, as spread indicators fell down to pre-crisis levels when the SNB started exceptional liquidity providing operations after October 2008. In August and September 2011 as well as in January 2015, spread indicators increased significantly at a time when the SNB took unconventional monetary policy actions, i.e., the introduction and the discontinuation of the EURCHF minimum exchange rate as well as the introduction of negative interest rates. In the years 2012 and 2013, trading activity was subdued due to the increase of the CHF reserves injected by the SNB (see discussion below) and bid-offer as well as effective spreads were on average approximately 10 bps, revealing reduced market liquidity. With market participants implementing the MoU to ensure the calculation of the SARON, spread indicators decreased in late 2013 back to few bps. Finally, it is worth noting that the bid-offer as well as the effective spread do not change after January 2015, when a tiered remuneration system for reserves with negative interest rates was introduced.

The development of price impact indicators is illustrated in Figure 3 Panel B. On average, the 5-minute price impact of a repo trade is 0.8 bps for the overall sample period and slightly higher in the liquidity-neutral period with 1.3 bps. The volatility of repo trade rates indicator shows a similar picture as the 5-minute price impact measure. On average, the volatility of repo trade rates (within the time interval) is 1.7 bps for the overall sample period and 3.2 bps in the liquidity-neutral period. For the excess liquidity period, the volatility of repo trade rates is lower, with 1.1 bps on average. Overall, it is important to note that both price impact measures develop quite similarly as transaction costs indicators. Thus, they peaked during the financial crisis and at the time when the SNB introduced negative interest rates and the EURCHF minimum exchange rate. However, they remained at low levels during the period with subdued trading activity in 2012 and 2013, while transaction cost indicators increased.

Quote and trade volumes: The size of the quote book, measured by the cash provider quote volume and the cash taker quote volume, is illustrated in Figure 5. The quoted volumes were approximately symmetric prior to the financial crisis and increased slightly over time. As shown, the quoted volumes changed only to some extent during the peak of the financial crisis. During the excess liquidity period, the cash provider volume almost doubled, while at the same time, the cash taker quote volume declined due to excess reserves in the system. Over time, the quoted volumes became even more imbalanced, as the cash provider quote volume increased while the cash taker quote volume remained very low, which goes along with a considerable increase in excess reserves (see Figure 6 Panel B). Consequently, the quoted volume indicate a structural change in the repo market. Whereas in the liquidity-neutral period the market was balanced with trading interest on both sides, does barely a functional market exist in the excess liquidity period as the trading interest is completely asymmetric.

The development of the trade volume is depicted in Figure 6 Panel A. The average trading volume between 2006 and 2016 is about CHF 3.0 bn. At the beginning of the sample period, trading activity was substantially livelier with a daily trade volume reaching a maximum of CHF 9.7 bn, while in the period with excess reserves, trading activity was subdued with an average daily trade volume of CHF 1.5 bn. In the negative interest rate period, the trade volume increased again to an average of CHF 2.9 bn, even though the amount of excess reserves increased further. This is due to the fact, that the introduction of the tiered remuneration system with negative interest rates created a new trading motivation and banks trade reserves to reduce the costs induced by negative interest rates.

Intraday pattern: Table 4 provides evidence that market liquidity indicators display distinct intraday patterns, which are particularly pronounced in the liquidity neutral period. Market liquidity tends to be low at the beginning and the end of a trading day, whereas it is relatively high during the day. For example, the average bid-offer spread at the market opening (closing) is around 12 (9) bps whereas it as about 6 bps during the trading day. In line with this, the size of the quote book is typically small in the early trading hours then increases relatively quickly reaching its peak at around 11 a.m. and declines gradually afterwards before collapsing shortly before the end of the business day. For the excess liquidity and the negative interest rate period, intraday patterns are also present but of a slightly lower magnitude.[23]

Intra-month pattern: Table 5 shows the intra-month pattern of market liquidity indicators. The table provides evidence that liquidity is affected by minimum reserve requirements set by the SNB. In the liquidity-neutral period, the fulfillment of the minimum reserve requirement was binding for banks and the last days of the minimum reserve requirement period (day of month: 16, 17, 18, and 19) are associated with higher transaction costs and price impacts. While spread indicators reveal 2-5 bps wider transaction costs, price impact indictors show more volatile repo rates by up to 2 bps on those dates. In the excess liquidity and the negative interest rate period, banks easily fulfill minimum reserves, and the minimum reserve requirement pattern no longer exits. Additionally, Table 5 reveals that market liquidity is typically also reduced at the end of the month, which is potentially due to bank's window dressing activities.

[23]Note that this could potentially also be due to the generally subdued trading activity.

Correlations: Table 6 shows pairwise correlation coefficients between various liquidity measures. The correlation coefficients are positive across all market liquidity indicators.[24] In particular, the correlation between the bid-offer spread and the effective spread is high with a correlation coefficient of approximately 0.7. Moreover, the correlation coefficients between the different groups of market liquidity indicators are also positive (correlation coefficients between 0.3 and 0.5) and indicate that transaction costs are positively related to price impact measures. Additionally, it is important to note that the correlation coefficients for quoted as well as traded volumes with transaction cost and price impact indicators are close to zero or even negative, which is in line with the findings in the related literature (see, e.g., Mancini, Ranaldo and Wrampelmeyer (2012)).

Availability of indicators: Not every market liquidity indicator can be calculated for every observation point. For example, to measure the bid-offer spread a cash provider quote and a cash taker quote is required. If one of the two is missing, the bid-offer spread cannot be calculated and appears as a missing observation in the dataset. Table 3 Column 7 indicates that this is the case for roughly 20% of all potential observation points. On the one hand, these missing observations occur during the beginning of the trading day (see Table 7). Especially, market liquidity indicators for the first observation of a business day (timestamp 07:53:30) can often not be calculated. On the other hand, Table 7 reveals that fewer market liquidity indicators can be calculated in the excess liquidity period. During this period, trading activity is reduced and cash taker quotes are rather scarce, reducing the availability of market liquidity indicators.

5 Determinants of liquidity

This section identifies the determinants of market liquidity. First, I motivate my hypotheses. Second, I define the estimated regressions and discuss the results. Finally, I subject my findings to several robustness checks.

5.1 Hypothesis

Positioning of interest rates in corridor: When the central bank increases the amount of reserves in the financial system the positioning of interest rates in the interest rate corridor of the central bank lowers towards the deposit rate (see e.g., Bech and Monnet (2015)). Consequently, the spread between the interbank rate and the rate at which banks can deposit reserves at the central bank is low. In a market where all participants have access to the central banks' deposit facility, this reduces price impact measures as all banks can deposit their excess reserves at the

[24] These correlation coefficients hint to a common underlying driver of liquidity. A principal component analysis is provided in Appendix A.3.

central bank and do not have to lend them in the interbank market at a market interest rate. Thus, I expect price impact measures to be low, if the spread between the interbank rate and the SNB's deposit rate is low.

Hypothesis 1: Price impact measures are positively related with the spread between the interbank rate and the SNB's deposit rate.

Minimum reserve requirements: The literature suggests that repo markets show distinct seasonal patterns due to minimum reserve requirements set by central banks.[25] Typically, calendar-based regularities due to minimum reserve requirements occur at the end of the maintenance period (Fecht, Nyborg and Rocholl, 2008). As the SNB requires banks to hold minimum reserves, market liquidity might also be affected by minimum reserve requirements, if the allocation of reserves matters. Consequently, I test whether market liquidity is reduced on the last days of the maintenance period (day of month: 16, 17, 18, and 19) using dummy variables (called MiRe). I expect market liquidity indicators to increase on those days in the liquidity-neutral period. As banks easily fulfill minimum reserve requirements in the excess liquidity period, minimum reserve requirements no longer matter for banks; hence, market liquidity should be unaffected at the end of the maintenance period.

Hypothesis 2: Market liquidity is reduced at the end of the minimum reserve requirement period in the liquidity-neutral period but unaffected in the excess liquidity period.

Risks: Market liquidity might be affected by the general risk sentiment in the financial system (Borio, 2000). Theoretical models predict that banks reduce lending in times of elevated aggregate risk, uncertainty, and asymmetric information (see e.g. Allen, Carletti and Gale (2009), Caballero and Krishnamurthy (2008), and Stiglitz and Weiss (1981)). These risks may also affect liquidity in the repo market. Consequently, I expect a negative risk sentiment in the global financial system to cause larger transactions costs and price impact indicators. As a measure of the global financial market's risk sentiment, I use the Chicago Board Options Exchange Volatility Index (VIX) as an explanatory variable.[26]

Hypothesis 3: Market liquidity deteriorates with a negative risk sentiment.

Fixed-rate full allotment: The SNB used the fixed-rate full allotment auction procedure from 28 October 2009 to 12 May 2010 to counter tensions in money markets during and after the financial crisis. As the SNB follows an open access policy and the majority of banks active on

[25]See, for example, Fecht, Nyborg and Rocholl (2008) for developments in the euro area and Hamilton (1996) as well as Bartolini, Bertola and Prati (2001) for the developments in the US.

[26]The VIX index measures the implied volatility of the S&P 500 index. Note that using the volatility index of the Swiss Market Index (VSMI) or the CHF Libor-OIS spread instead of the VIX would lead to very similar results (see robustness checks).

the trading platform can participate in SNB's open market operations (Kraenzlin and Nellen, 2015), the fixed-rate full allotment auction procedure ensured banks access to reserves in the primary market. Hence, with the fixed-rate full allotment auction procedure, there was no need for banks to reallocated reserves in the interbank market anymore and as a consequence, the trade volume in the interbank market declined substantially. Therefore, I expect the fixed-rate full allotment auction procedure also to affect transaction cost and price impact indicators.

Hypothesis 4: The fixed-rate full allotment auction procedure affected market liquidity indicators.

Calendar-based regularities and MoU: Calendar-based regularities might not only occur at the end of the minimum reserve requirement period but also on specific disclosure dates, such as the month-, quarter-, and year-end due to banks' window dressing (see, e.g. Feldberg (2015)). Hence, I include dummy variables (called Ultimo) for the year-, quarter-, and month-end in the regression analysis. Moreover, I include a dummy variable (called MoU) for the period after 1 October 2013, when five major market participants in the CHF repo market signed the MoU to place cash provider and taker quotes with a bid-offer spread not exceeding 5 bps to facilitate the calculation of the SARON (see discussion in Section 3.5).

Control variables: First, I use day-of-the-week dummy variables (i.e. a dummy for every weekday), a dummy variable for the day of a monetary policy announcement as well as a dummy variable for the day before a national holiday. Second, I control for the amount of reserves in the financial system. Third, I account for (i) the exceptional liquidity measures implemented by the SNB between 3 August and 10 September 2011 and (ii) the period when the SNB conducted liquidity-providing repo transactions at negative rates (24 August 2011 until 24 May 2012) using two dummy variables.

5.2 Regression analysis

To assess the determinants of market liquidity indicators I run two ordinary least squares (OLS) regression specifications.[27] First, I assess the determinants of liquidity on a daily basis. By analyzing liquidity on a daily basis, I account for the fact that during the excess liquidity period market activity was subdued. Second, I run a regression analysis using all available intraday observations of market liquidity indicators. By analyzing liquidity on an intraday basis, I am able to control for possible intraday patterns in market liquidity indicators.

[27]Note that estimating a vector autoregression model would also be a possibility. However, as in the market under consideration, reserves are exchanged on an overnight basis, most effects are only prevalent for one time period. Moreover, most independent variables are dummy variables. Thus, I focus on an OLS regression.

5.2.1 Data

For both regress specifications, the dataset described in Section 4 is slightly adjusted. First, to control for the change in the platform provider as of 2 May 2014, the sample period is reduced to the period from 3 April 2006 to 2 May 2014 (see discussion in Section 3.1). Second, I apply the natural logarithm for volumes. Third, I define the positioning of repo rates in relative terms as the width of the SNB's interest rate corridor changed over time (see Equation 8).

$$\text{Positioning in corridor}_t = \frac{i_t^{\text{IB}} - i_t^{\text{SNB deposit}}}{i_t^{\text{SNB lending}} - i_t^{\text{SNB deposit}}} \tag{8}$$

Fourth, for the regression analysis using daily data market liquidity indicators are adjusted as follows: For the quoted bid-offer spread, the effective spread and the price impact indicator, simple averages of all available intraday observations are calculated. For the volatility of repo trade rates, the daily series is generated by calculating the daily standard deviation of repo rates.

5.2.2 Analysis of daily data

For the analysis of market liquidity indicators on a daily basis, I run the following OLS regression:

$$MLI_t = \alpha + \sum_{n=1}^{N} \beta_n \ \mathrm{x}_{t,n} + \epsilon_t \tag{9}$$

The dependent variable, market liquidity indicator (MLI_t), is the bid-offer spread, the effective spread, the price impact of repo trades, and the volatility of repo trade rates. Explanatory variables ($x_{t,n}$) used are stated in Subsection 5.1 and described in Table 2. To eliminate endogeneity issues all independent variables apart from dummy variables are lagged, as current independent variables are not influenced by future dependent variables. Finally, I use heteroskedasticity and autocorrelation robust standard errors to control for a potential correlation of the error terms, using the Newey and West (1987) correction.

The regression results are reported in Table 8. With respect to Hypotheses 1, the regression results reveal that the relative positioning of interest rates affects price impact and transaction costs measures. The positive regression coefficients for price impact measures indicate that when interest rates are close to the SNB's deposit rate, the uncertainty about repo rates declines and price impact measures show low values. Moreover, also transaction cost indicators are positive and statistically significant, indicating that transaction costs are low when interest rates are close to the SNB's deposit rate. In terms of the economic magnitude, a reduction of interbank rates from the middle of the interest rate corridor to the deposit rate decreases spread indicators by around 13 bps, the volatility of repo rates by about 6 bps and the 5-minute price impact indicator by about 1.3 bps.

The coefficients for end of minimum reserve requirement period dummy variables are positive and statistically significant in the first sample period. The economic and statistical magnitude is predominantly increasing towards the end of the maintenance period, indicating elevated tensions towards the end of the minimum reserve requirement period. For example, the volatility of repo trade rates on the last day of the minimum reserve requirement period is, ceteris paribus, 5.5 bps higher than on any other business day, whereas the corresponding regression coefficient for the second last day indicates a value of 3.3 bps. With excess reserves, the allocation of reserves at the end of the maintenance period no longer plays a role, because banks easily fulfill the minimum reserve requirements. Therefore, the corresponding regression coefficients lack statistical and economic significance in the excess liquidity period. Overall, these results confirm Hypothesis 2.

There is strong evidence that the risk sentiment in the global financial system affects liquidity in the CHF repo market negatively, supporting Hypothesis 3. For all market liquidity indicators, the regression coefficient is statistically significant and positive. Hence, an increase in the VIX is associated with higher transaction costs as well as price impact indicators. In terms of the economic magnitude, a one standard deviation increase in the VIX increases the bid-offer spread as well as the effective spread by approximately 2.4 bps, the price impact of a repo trade by about 0.4 bps and the daily volatility of repo trade rates by about 1.8 bps, respectively.

In the period when the SNB conducted the fixed-rate full allotment auction procedure, the quoted bid-offer spreads was 6.2 bps and the effective spread 6.7 bps lower (Hypothesis 4). Also the coefficients for the price impact as well as the volatility of repo trade rates measure are statistically significant and negative. Thus, the regression results provide evidence that the SNB policy ensured banks' access to central bank money in the primary market and thereby also affected interbank market conditions. As banks were not required to trade reserves in the interbank market anymore, but could simply participate in SNB's auctions and receive a full allotment with certainty, the overall interbank market activity declined substantially and transaction cost and price impact indicators show low values.

The regression results also provide evidence that market participants indeed followed the MoU to place cash provider and taker quotes with a bid-offer spread not exceeding 5 bps. The corresponding regression coefficient is statistically and economically highly significant for the quoted bid-offer spread as well as the effective spread with around 7 bps. Moreover, the regression coefficients for the year-end is economically significant for transaction costs, however, statistically not significant while price impact measures indicate no reduced market liquidity at those dates. Consequently, there is some evidence that market participants place their quotes more carefully on the year-end, but price changes after repo trades are not more pronounced compared to other business days.

5.2.3 Analysis of intraday data

The determinants of liquidity can also be analyzed using all available intraday data by running the following OLS regression:

$$MLI_t = \alpha + \sum_{n=1}^{N} \beta_n \ \mathrm{x}_{t,n} + \sum_{i=1}^{I} \gamma_i \ \mathrm{FE}_{t,i} + \epsilon_t \tag{10}$$

As before, the dependent variable, market liquidity indicator (MLI_t), is the bid-offer spread, the effective spread, the price impact of repo trades, and the volatility of repo trade rates. In addition to the explanatory variables used in the analysis of daily data, I use time-of-day (indexed by i) dummy variables (FE) to account for intraday patterns in market liquidity and an unbalanced number of observations across the day. Moreover, I use standard errors clustered by business day to control for a potential correlation of the error terms.

The regression results for the OLS regression analysis using all available intraday data are reported in Table 9. The regression results using intraday data turn out to be very similar compared to the regression analysis using daily data. Hence, the findings for Hypotheses 1–4 can also be confirmed using intraday data. Between the two regression specifications, the most notable differences are that the regression coefficients for the year-end and the month-end disclosure date are statistically significant on a 5% and on a 10% significance level for the bid-offer spread. Moreover, the regression results indicate that during the period when market participants followed the MoU the volatility of repo trade rates was elevated while spread coefficients are still negative and statistically significant. Additionally, this regression specification also shows the intraday pattern of market liquidity indicators. The dummy variables provide strong evidence that market liquidity is low at the beginning and the end of a trading day, whereas market liquidity is relatively high during the trading day.

5.3 Robustness

Risk variable: Table 10 shows the regression analysis with daily data using the volatility index of the Swiss Market Index (VSMI) instead of the VIX, while in Table 11 the CHF Libor-OIS spread is used as a measure for the risk sentiment. The regression coefficients for both risk variables are positive and statistically significant for all market liquidity indicators, as in the baseline analysis. Thus, Hypothesis 3 can also be confirmed using the VSMI or the CHF Libor-OIS spread instead of the VIX.

Lagged dependent variable: Table 12 shows the OLS regression results with daily data using a lagged dependent variable as an explanatory variable. For all market liquidity indicators, the lagged dependent variable is positive and statistically significant, suggesting that market liquidity indicators have a moving component. Compared to the baseline analysis, the most notable difference in this regression specification is that the dummy variables at the end of the minimum reserve requirement period have less statistical significance. However, also with this regression specification, the findings with regard to Hypotheses 1–4 remain valid.

Sample periods: Table 13 and 14 show the OLS regression results with daily data for the liquidity neutral and the excess liquidity period separately. Compared to the baseline analysis, the most important change is that in the liquidity neutral period, the coefficients for the positioning of interest rates in the interest rate corridor are mostly positive, however, statistically not significant. This changes in the excess liquidity period, for which the coefficients are statistically and economically significant for all market liquidity indicators.

Availability of intraday market liquidity indicators: As seen in Section 4.4, intraday market liquidity indicators are not always available. With a probit regression, I assess whether a market liquidity indicator's availability can be explained. To do so, a binary dependent variable is generated (MLI_t^{av}), which takes the value one if a market liquidity indicator is available at time t and zero otherwise.

$$Prob(MLI_t^{av} = 1) = \Phi(\sum_{n=1}^{N} \beta_n \ \mathrm{x}_{t,n} + \sum_{i=1}^{I} \gamma_i \mathrm{FE}_{t,i}) \tag{11}$$

In addition to the independent variables used in the OLS regressions, the probit regression contains the cash provider quote volume, the cash taker quote volume, and the trade volume as explanatory variables.[28] Table 15 provides the probit regression results.[29] Most importantly, the table reveals that the availability of market liquidity indicators can be explained to a considerable extent (pseudo R-squared between 0.4 and 0.6). Moreover, the regression results indicate that the probability to observe a market liquidity indicator is positively and statistically significantly related with the cash provider quote volume and the cash taker quote volume, which intuitively makes sense. This illustrates that with higher excess reserves in the financial system fewer market liquidity indicators can be calculated, as only very few cash taker quotes are available anymore. Moreover, market liquidity indicators are also positive and statistically significantly related with the trade volume, expect the bid-offer spread which is negative and significantly related. Finally, it is worth noting that the end of the minimum reserve requirement period affects the availability of market liquidity indicators in the liquidity neutral period negatively. Thus, on the last days of the minimum reserve requirement period market liquidity indicators are not only lager but also less likely to be observed.

[28] To eliminate endogeneity issues, these variables are lagged as before.

[29] Note that the sign of the coefficient in a probit regression gives the sign of the according marginal effect (Cameron and Trivedi, 2005). Hence, the interpretation of the probit regression results focuses on the sign and the significance of the coefficient, which determines the direction of the corresponding marginal effect.

Sample selection model: As the availability of intraday market liquidity indicators can be explained, an OLS analysis of all available intraday market liquidity indicators may contain a sample selection problem. To control for this, I apply a Heckman selection model to validate the findings from the intraday OLS regression. In a first step the Heckman selection model combines a selection mechanism to predict the availability of a market liquidity indicator and in a second step assesses the determinants of market liquidity. In the Heckman selection model, the selection equation is

$$m_t^* = \boldsymbol{\gamma} \boldsymbol{w}_t + \mu_t \tag{12}$$

and the regression model

$$MLI_t = \boldsymbol{\beta} \boldsymbol{x}_t + \epsilon_t \tag{13}$$

where the error terms ϵ_t and μ_t are assumed to be bivariate normal $[0,0,1,\tau_\epsilon,\ \rho]$ and m_t^* is not observed. The probability of observing a market liquidity indicator ($m_t = 1$) is Prob($m_t = 1$) = $\Phi(\gamma^{'} w_t)$ while the probability of not observing a market liquidity indicator is Prob($m_t = 0$) = 1-$\Phi(\gamma^{'} w_t)$, where Φ is the standardized normal cumulative distribution function. In the selected sample, the following equation applies:

$$E[MLI_t \mid m_t = 1]_t = \boldsymbol{\beta} \boldsymbol{x}_t + \tau_\epsilon \rho \lambda(\gamma^{'} w_t) \tag{14}$$

In the selection equation, I use the cash provider quote volume, the cash taker quote volume, and the trade volume as additional variables explaining the availability of market liquidity indicators.[30] The Heckman regression is estimated using the two-step procedure, which provides efficient estimates of the parameters (see Cameron and Trivedi (2005)) and standard errors are calculated based on the two-step variance estimator derived by Heckman. The regression results are reported in Table 16. The signs of the coefficients in the selection equation are in line with the findings in the probit regression. Moreover, the regression coefficients in the main equation are generally in line with the findings from the intraday OLS regression. Compared to the OLS regression, the most notable differences are that the Heckman regression provides more statistical evidence of reduced market liquidity at the end of the minimum reserve requirement period as well as at specific disclosure dates.

[30] As shown in the probit model, these variables explain the availability of a market liquidity indicator quite good.

6 Conclusion

This paper estimates and analyses liquidity in the CHF overnight repo market. Based on standard measures of transaction costs and price impacts, repo market liquidity is characterized prior to, during, and after the financial crisis, as well as in a positive and a negative interest rate environment.

The key stylized facts of repo market liquidity can be summarized as follows: Frist, I document that liquidity in the CHF overnight repo market disappeared during the financial crisis. Second, market liquidity indicators have distinct intraday patterns, with low liquidity in the early and late trading hours. Third, I find that with excess reserves in the financial system after the financial crisis, the market structure of the interbank market changed considerably. Quoted volumes in the interbank market became imbalanced towards more cash providers and the trade volume declined substantially. Along with this, fewer market liquidity indicators can be calculated as only few banks act as cash takers in the repo market. Additionally, the regression results indicate that market liquidity is affected by the SNB's monetary policy framework. In this regard, I find that market liquidity is reduced at the end of the minimum reserve requirement period before the financial crisis. Moreover, when interest rates trade close to the SNB's deposit rate, price impact indicators are low as there is little uncertainty about repo rates. This is due to the fact, that all market participants in the CHF repo market have a sight deposit account at the SNB and that depositing excess reserves at the central bank is an available outside option for all banks. Furthermore, I find evidence that a negative risk sentiment in the global financial system affects liquidity in the CHF repo market negatively.

The analysis of market liquidity has several policy implications. First, I show that accommodative monetary policy affects liquidity in interbank repo markets. If reserves are in excess, quoted volumes become asymmetric towards more cash provider quotes and the trade volume declines substantially. Hence, compared to a pre-crisis environment, the importance of the central bank as a market participant has increased. Second, my analysis shows that for the definition and the design of robust benchmark rates, regulators need to consider that trading activity is subdued and cash taker quotes are rather rare in an environment with excess reserves. Hence, it is important to consider all available quoted repo rates and trades for the calculation of reliable benchmarks and not to apply quote and trade filters that are too strict. Third, this paper contributes to the general understanding of repo markets, which might become generally more important in the future, since repo rates are considered to be potential alternatives for unsecured monetary policy target rates. Finally, with the data on repo market liquidity at hand, future research can be done. In particular, it might be worth identifying the impact of regulatory reforms (such as the Basel III Leverage Ratio and the Liquidity Coverage Ratio) on banks' repo market activity.

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A Appendix

A.1 Figures

Figure 1: Stylized time line

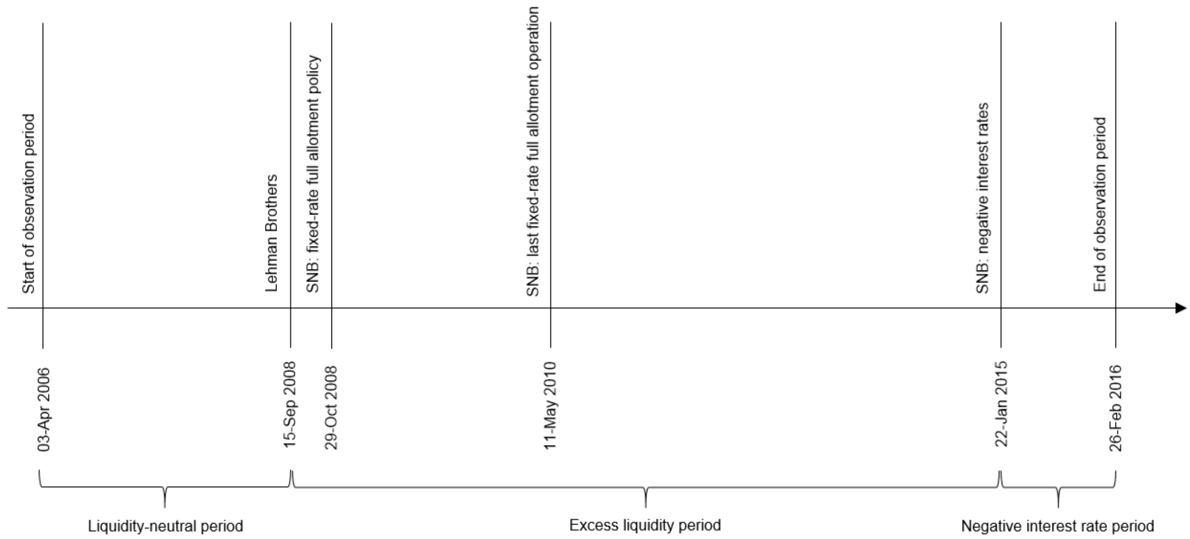

Figure 1 shows the different phases of monetary policy implementation.

Figure 2: SNB's open market operations

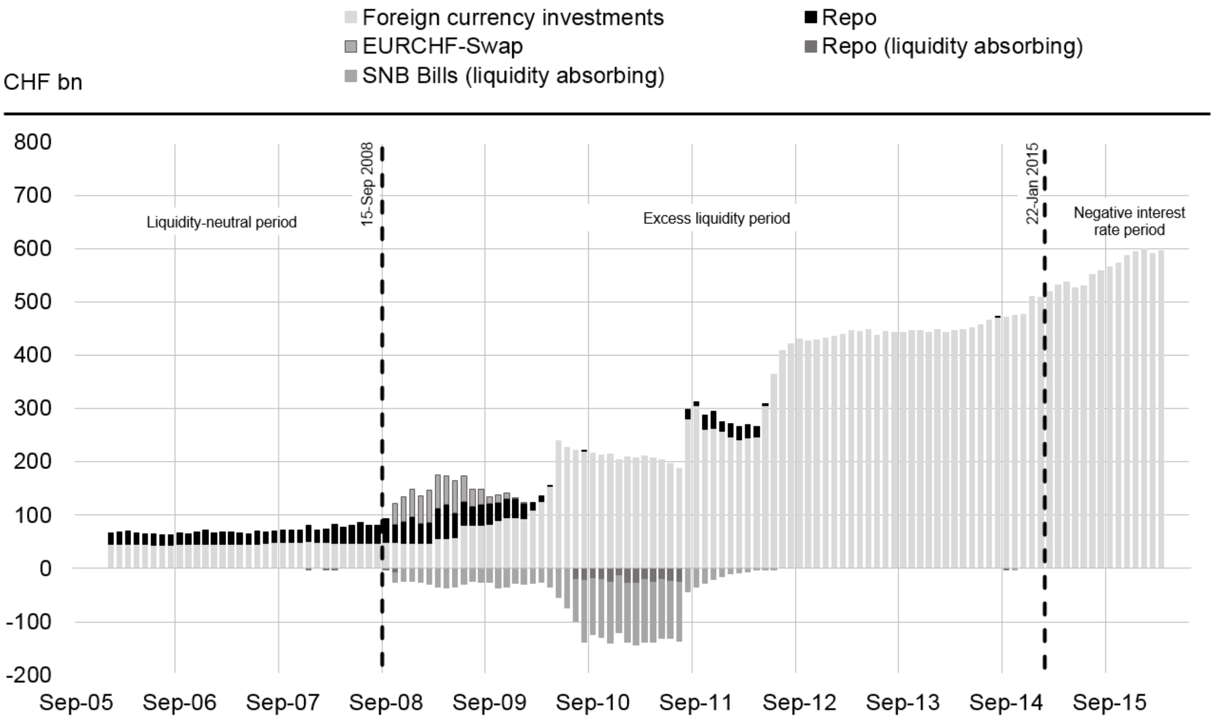

Figure 2 illustrates the outstanding open market operations of the SNB. Source: Data portal of the SNB.

Figure 3: Market liquidity indicators

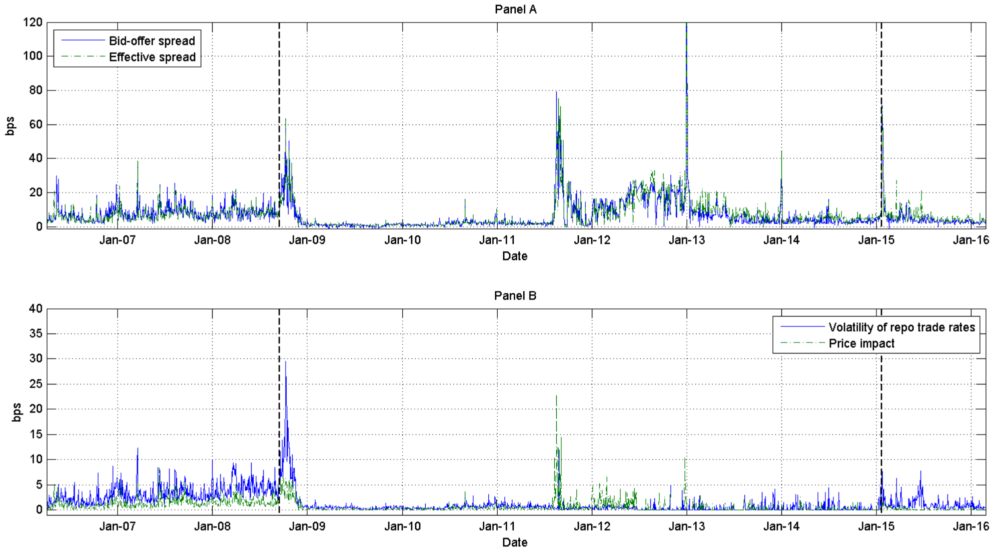

Figure 3 illustrates market liquidity indicators over the sample period. Panel A shows the bid-offer spread and the effective spread. Panel B depicts the volatility of repo trade rates as well as the 5-minute price impact of repo trades. Daily averages are illustrated. The vertical line indicates the different phases of monetary policy implementation. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008, the excess liquidity period from 15 September 2008 to 21 January 2015, and the negative interest rate period from 22 January 2015 to 26 February 2016. The specification of the market liquidity indicators is given in Section 4.2.

Figure 4: State variables I

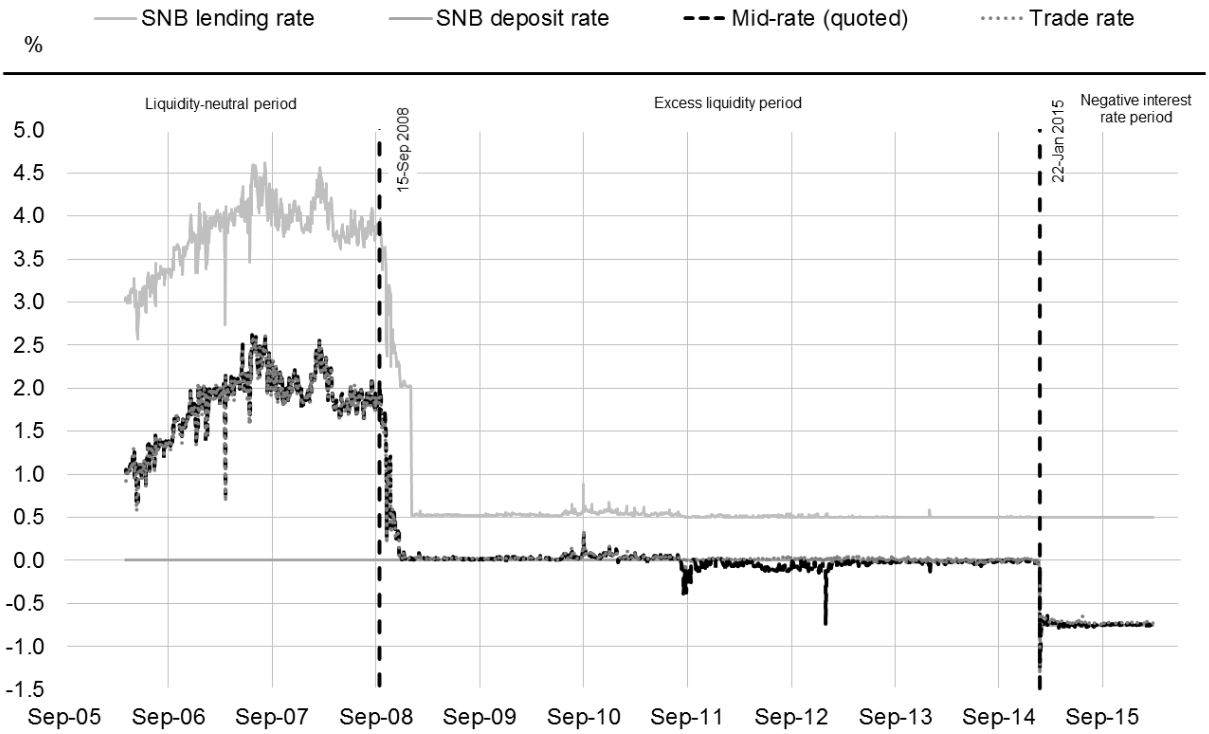

Figure 4 illustrates the development of repo rates (quoted mid-rates as well as trade rates) and the SNB's standing facility rates. Daily averages are illustrated. The vertical line indicates the different phases of monetary policy implementation. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008, the excess liquidity period from 15 September 2008 to 21 January 2015, and the negative interest rate period from 22 January 2015 to 26 February 2016.

Figure 5: State variables II

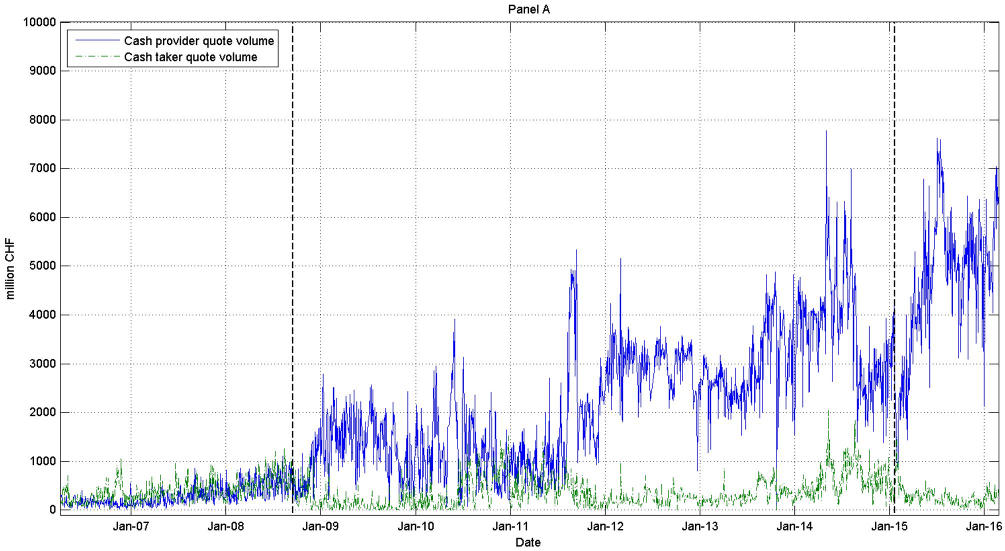

Figure 5 shows the cash provider quote volume and the cash taker quote volume. Daily averages are illustrated. The vertical line indicates the different phases of monetary policy implementation. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008, the excess liquidity period from 15 September 2008 to 21 January 2015, and the negative interest rate period from 22 January 2015 to 26 February 2016.

Figure 6: State variables III

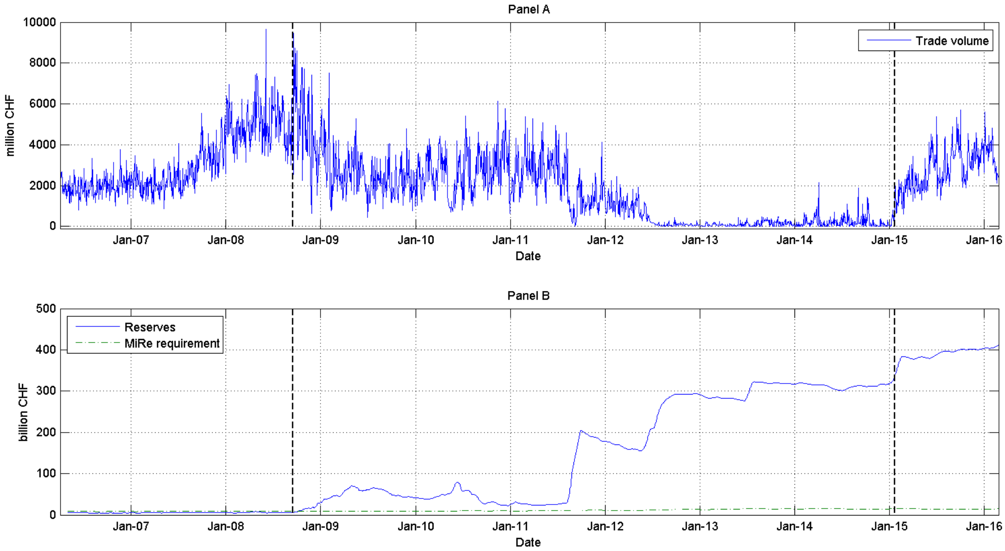

Figure 6 Panel A illustrates the daily trade volume in the overnight repo market. Panel B shows the level of reserves (20-day moving average) and the minimum reserve requirements. The vertical line indicates the different phases of monetary policy implementation. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008, the excess liquidity period from 15 September 2008 to 21 January 2015, and the negative interest rate period from 22 January 2015 to 26 February 2016.

A.2 Tables

Table 1: Trade and quote frequencies

	mean	median	sd	min	max	count
Time between trades (in minutes)	8.5	2.7	17.8	0.0	429.2	83’198
Number of trades per day	33.5	34.0	25.4	1.0	135.0	2’496
Quote active time (in minutes)	55.7	10.0	106.8	0.0	614.6	262’247
Number of quotes per day	69.6	64.0	45.2	1.0	256.0	2’496

Table 1 provides descriptive statistics of trade and quote frequencies. The sample period ranges from 3 April 2006 to 26 February 2016.

Table 2: Description of variables

Abbreviation	Unit	Variable name
Market liquidity indicators		
BOS	basis points	Bid-offer spread
EFS	basis points	Effective spread
PMI	basis points	Price impact of repo trades
VOL	basis points	Volatility of repo trade rates
Independent variables and market characteristics		
QCP	mn CHF	Cash provider quote volume
QCT	mn CHF	Cash taker quote volume
TRV	mn CHF	Trade volume
VIX	percentage points	Chicago Board Options Exchange Volatility Index
VSMI	percentage points	Volatility Index of the Swiss Market Index (SMI)
Libor-OIS	percentage points	Libor-OIS spread (three-month maturity)
MiRe (1d)	dummy	One if last day of minimum reserve requirement period
MiRe (2d)	dummy	One if second-last day of minimum reserve requirement period
MiRe (3d)	dummy	One if third-last day of minimum reserve requirement period
MiRe (4d)	dummy	One if fourth-last day of minimum reserve requirement period
Fixed-rate full allotment	dummy	One for period 29 October 2008 – 12 May 2010
Orderflow	number of trades	1 (-1) cash taker (provider) initiated
Control variables		
Month-end	dummy	One if month-end
Quarter-end (add-on)	dummy	One if quarter-end
Year-end (add-on)	dummy	One if year-end
MoU	dummy	One for period 1 October 2013 – end of dataset
Exceptional liquidity measures	dummy	One for period 3 August 2011 – 10 September 2011
SNB quotes negative	dummy	One for period 24 August 2011 – 24 May 2012
Pre-holiday	dummy	One if the following day is a holiday
MPA	dummy	One if day of monetary policy announcement

Table 3: Descriptive statistics

	mean	p50	min	max	count	NaN	N
Panel A: Overall sample period							
Bid-offer spread (bps)	6.78	3.50	-140.00	160.00	17722	21.1%	22464
Effective spread (bps)	6.33	3.65	0.00	157	14693	34.6%	22464
Price Impact (bps)	0.82	0.17	0.00	63.00	13934	44.2%	24960
Volatility (bps)	1.70	0.58	0.00	60.83	16157	35.5%	24960
Cash provider quote volume (mn CHF)	2029.56	1600.00	0.00	12809.00	24960	0.0%	24960
Cash taker quote volume (mn CHF)	359.66	250.00	0.00	2885.00	24960	0.0%	24960
Trade volume (mn CHF)	206.74	88.00	0.00	3516.00	24960	0.0%	24960
Trade rate (%)	0.52	0.03	-1.72	2.69	16157	35.3%	24960
Orderflow (number of trades)	0.35	1.00	-31.00	37.00	16157	35.3%	24960
Panel B: Liquidity neutral period							
Bid-offer spread (bps)	7.78	5.00	-10.00	120.00	4618	16.6%	5535
Effective spread (bps)	7.13	5.20	0.00	102.33	5014	9.4%	5535
Price Impact (bps)	1.31	0.75	0.00	39.17	4924	19.9%	6150
Volatility (bps)	3.20	2.29	0.00	49.20	5158	16.1%	6150
Cash provider quote volume (mn CHF)	295.85	205.50	0.00	1900.00	6150	0.0%	6150
Cash taker quote volume (mn CHF)	396.82	315.00	0.00	2385.00	6150	0.0%	6150
Trade volume (mn CHF)	308.50	200.00	0.00	3516.00	6150	0.0%	6150
Trade rate (%)	1.81	1.88	0.00	2.69	5158	16.1%	6150
Orderflow (number of trades)	-1.82	-1.00	-31.00	37.00	5158	16.1%	6150
Panel C: Excess liquidity period							
Bid-offer spread (bps)	6.79	3.00	-40.00	160.00	10896	24.4%	14418
Effective spread (bps)	5.88	2.00	0.00	156.00	7599	47.3%	14418
Price Impact (bps)	0.68	0.00	0.00	63.00	6941	56.7%	16020
Volatility (bps)	0.98	0.35	0.00	60.83	8752	45.4%	16020
Cash provider quote volume (mn CHF)	2232.23	2185.00	0.00	8049.00	16020	0.0%	16020
Cash taker quote volume (mn CHF)	360.77	250.00	0.00	2885.00	16020	0.0%	16020
Trade volume (mn CHF)	154.06	15.00	0.00	3340.00	16020	0.0%	16020
Trade rate (%)	0.07	0.02	-0.75	2.12	8752	45.4%	16020
Orderflow (number of trades)	0.59	1.00	-31.00	30.00	8752	45.4%	16020
Panel D: Negative interest rate period							
Bid-offer spread (bps)	4.76	3.00	-140.00	98.00	2208	12.1%	2511
Effective spread (bps)	6.03	4.17	0.00	157	2080	17.2%	2511
Price Impact (bps)	0.16	0.00	0.00	12.50	2069	25.8%	2790
Volatility (bps)	1.06	0.38	0.00	43.30	2247	19.5%	2790
Cash provider quote volume (mn CHF)	4687.43	4900.50	0.00	12809.00	2790	0.0%	2790
Cash taker quote volume (mn CHF)	271.33	250.00	0.00	1850.00	2790	0.0%	2790
Trade volume (mn CHF)	284.89	200.00	0.00	2165.00	2790	0.0%	2790
Trade rate (%)	-0.72	-0.72	-1.72	0.02	2247	19.5%	2790
Orderflow (number of trades)	4.39	3.00	-9.00	22.00	2247	19.5%	2790

Table 3 provides descriptive statistics of market liquidity indicators and general market characteristics. The specification of the market liquidity indicators is given in Section 4.2. The overall sample (Panel A) ranges from 3 April 2006 to 26 February 2016. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008 (Panel B), the period with excess reserves ranges from 15 September 2008 to 21 January 2015 (Panel C), and the period with negative interest rates ranges from 22 January 2015 to 26 February 2016 (Panel D).

Table 4: Intraday pattern

Panel A: Liquidity neutral period	07:53:30	08:47:00	09:40:30	10:34:00	11:27:30	12:21:00	13:14:30	14:08:00	15:01:30	15:55:00
Bid-offer spread	11.7	7.5	5.9	6.0	6.0	7.3	7.3	6.5	9.4	-
Effective spread	12.5	8.6	6.4	5.9	5.7	5.7	6.8	6.3	6.4	12.3
Volatility	2.8	2.2	2.9	2.5	2.3	1.9	1.9	2.9	4.3	7.2
Price impact	0.0	1.4	1.0	0.8	0.8	0.9	0.7	1.1	2.0	3.2
Cash provider quote volume	11.8	367.1	414.7	393.5	382.8	346.5	323.6	337.4	281.9	99.3
Cash taker quote volume	9.6	547.5	595.2	576.9	528.5	468.4	454.9	442.3	292.9	52.1
Panel B: Excess liquidity period	**07:53:30**	**08:47:00**	**09:40:30**	**10:34:00**	**11:27:30**	**12:21:00**	**13:14:30**	**14:08:00**	**15:01:30**	**15:55:00**
Bid-offer spread	7.4	6.7	6.2	6.0	6.1	6.1	6.5	6.7	7.4	-
Effective spread	1.8	6.0	5.7	6.8	6.2	5.3	5.2	5.5	5.4	6.8
Volatility	0.1	0.8	1.0	0.9	0.9	0.9	0.9	0.9	1.1	1.7
Price impact	0.2	0.8	0.6	0.5	0.5	0.4	0.7	0.7	0.9	1.5
Cash provider quote volume	321.7	2’406.6	2’625.5	2’624.2	2’582.6	2’424.8	2’397.5	2’410.7	2’387.1	2’141.6
Cash taker quote volume	44.9	478.9	502.7	467.7	437.3	393.1	380.9	361.4	310.3	230.3
Panel C: Negative interest rate period	**07:53:30**	**08:47:00**	**09:40:30**	**10:34:00**	**11:27:30**	**12:21:00**	**13:14:30**	**14:08:00**	**15:01:30**	**15:55:00**
Bid-offer spread	7.9	4.9	3.9	4.0	4.2	4.3	4.7	3.9	4.8	-
Effective spread	3.8	6.5	6.7	7.2	6.5	5.4	5.6	5.1	5.2	6.3
Volatility	0.2	1.0	2.0	1.6	1.3	0.6	0.6	0.7	0.8	0.9
Price impact	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.2	0.2
Cash provider quote volume	2’501.6	5’320.5	5’564.6	5’511.1	5’390.1	4’976.8	4’741.8	4’715.2	4’474.7	3’678.0
Cash taker quote volume	85.2	327.3	340.8	328.8	309.2	293.1	279.6	282.5	267.8	199.0

Table 4 shows the intraday pattern of different market liquidity indicators. Quoted volumes are in mn CHF. All other variables are in bps. Simple averages of available observations are reported. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008 (Panel A), the period with excess reserves ranges from 15 September 2008 to 21 January 2015 (Panel B), and the period with negative interest rates ranges from 22 January 2015 to 26 February 2016 (Panel C). The specification of the market liquidity indicators is given in Section 4.2.

Table 5: Intra-month pattern

	(1) BOS	(2) EFS	(3) PIM	(4) VOL	(5) BOS	(6) EFS	(7) PIM	(8) VOL	(9) BOS	(10) EFS	(11) PIM	(12) VOL
day 2	0.33	0.84	0.22	-0.29	-0.90	0.28	-0.11	-0.00	1.51	2.04*	-0.06	0.01
day 3	-0.07	0.01	0.14	-0.01	-0.29	0.76	0.21	0.05	1.33	1.96**	-0.11	-0.39
day 4	0.50	0.11	0.04	-0.26	-1.61	-0.45	-0.20	-0.36	1.22	0.72	-0.12	-0.52*
day 5	0.12	1.09	0.15	0.11	-1.13	0.19	0.15	-0.13	1.24	1.02	-0.15	-0.03
day 6	0.33	1.52	0.27	0.03	-0.54	0.61	-0.01	-0.05	1.91*	1.68	-0.07	-0.51**
day 7	0.17	0.18	0.01	-0.38	-0.52	0.66	-0.04	-0.07	2.10	2.50*	-0.17	-0.27
day 8	0.61	0.38	0.22	-0.15	-0.55	1.28	-0.01	0.24	1.90	2.38*	-0.10	-0.21
day 9	0.38	0.78	0.46	-0.23	-0.67	0.91	0.02	0.12	0.97	1.84*	-0.07	-0.41
day 10	1.20	1.84	0.35	-0.02	-1.06	1.22	0.21	0.53	1.11	1.41	-0.09	-0.29
day 11	1.10	0.97	0.43	0.30	-1.59	-0.20	-0.11	-0.21	0.20	0.99	-0.13	-0.61**
day 12	2.53*	2.36*	0.39	0.07	-0.46	0.48	-0.06	-0.26	0.39	0.80	-0.11	-0.24
day 13	1.97*	2.51*	0.53	0.39	0.03	0.65	-0.06	0.10	0.11	0.31	-0.06	-0.67**
day 14	1.32	1.67	0.40	0.63	-0.79	0.18	-0.09	-0.12	0.46	0.63	-0.15	-0.63**
day 15	1.40	1.58	0.82**	0.73	-1.23	0.08	-0.00	-0.03	1.29**	1.30	-0.01	-0.44
day 16	1.72	2.42**	0.68*	0.54	-0.59	0.57	-0.04	-0.18	1.04	1.05	-0.06	-0.70***
day 17	2.22*	2.73**	0.42	0.67	-0.66	0.99	0.27	0.38	0.62	1.18*	-0.01	-0.09
day 18	4.58***	3.01***	0.69**	0.92	-0.63	1.74	0.55	-0.02	-1.48	2.36	-0.09	0.20
day 19	2.75*	4.20**	1.02**	1.80**	-0.56	0.80	0.37	-0.14	0.15	1.14	-0.08	0.27
day 20	-0.08	0.49	0.13	-0.17	-1.55	-0.23	-0.05	-0.02	0.66	0.60	0.04	-0.40
day 21	-1.05	-0.59	0.10	-0.66	-1.02	0.23	-0.14	-0.14	0.29	0.65	-0.13	-0.52
day 22	-1.10	-0.86	-0.25	-0.54	0.13	2.77	0.01	0.06	7.02	8.44	0.11	-0.20
day 23	-0.40	-0.47	0.11	-0.50	0.79	1.29	0.02	0.10	6.30	4.86	-0.00	-0.09
day 24	-0.34	-0.35	0.22	-0.76	0.51	1.28	0.31	0.09	1.19	0.48	-0.02	-0.47
day 25	-0.55	-0.45	-0.00	-0.55	-1.18	0.76	0.19	-0.24	1.07*	1.27	-0.08	-0.14
day 26	0.63	0.45	0.19	-0.41	2.08	2.26	-0.04	-0.01	8.28	6.18	0.03	0.17
day 27	1.06	1.23	0.34	0.02	-0.21	0.37	-0.03	-0.19	4.50	3.73	-0.07	-0.06
day 28	1.53	1.78	0.26	-0.03	0.51	0.69	0.05	-0.08	3.77	2.17	-0.18	-0.33
day 29	1.43	1.89	0.37	0.54	-0.38	0.62	0.10	0.06	2.04	1.51	0.05	0.05
day 30	0.90	1.69	0.09	0.44	0.65	0.86	0.23	0.41	1.28*	0.33	0.06	-0.35
day 31	2.92*	3.16*	0.63	0.93	6.46**	5.45**	0.74*	0.17	3.76*	2.54	0.05	-0.14
Constant	11.14***	12.79	-0.12	2.69	8.01***	1.91*	0.06	0.05	6.41***	2.24***	0.13	0.40
Observations	4618	5014	4924	5158	13104	9679	9010	10999	2208	2080	2069	2247
Adjusted R^2	0.068	0.129	0.142	0.208	0.015	0.008	0.009	0.006	0.061	0.029	0.000	0.013
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 5 shows the intra-month (rows) pattern of different market liquidity indicators (columns). Market liquidity indicators are in bps. Column 1–4 show market liquidity indicators for the liquidity neutral period (lasting from 3 April 2006 to 14 September 2008), Column 5–8 show market liquidity indicators for the excess liquidity period (lasting from 15 September 2008 to 21 January 2015), and Column 9–12 show market liquidity indicators for the negative interest rate period (lasting from 22 January 2015 to 26 February 2016). The following abbreviations are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). The specification of the market liquidity indicators is given in Section 4.2. Time-of-day fixed effects are not reported. Standard errors are clustered by business day. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 6: Correlations

	BOS	EFS	PIM	VOL	QCP	QCT	TRV
BOS	1.000						
EFS	0.686	1.000					
PIM	0.404	0.297	1.000				
VOL	0.280	0.462	0.399	1.000			
QCP	-0.016	0.030	-0.143	-0.234	1.000		
QCT	-0.127	-0.019	-0.055	0.013	0.074	1.000	
TRV	-0.043	-0.055	0.118	0.200	-0.168	0.114	1.000
Observations	24960						

Table 6 shows correlation coefficients between different market liquidity indicators. The following abbreviations are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), volatility of repo trade rates (VOL), quoted volume cash provider (QCP), quoted volume cash taker (QCT), and trade volume (TRV). The sample period ranges from 3 April 2006 to 26 February 2016. The specification of the market liquidity indicators is given in Section 4.2.

Table 7: Availability of market liquidity indicators

Panel A: Liquidity neutral period	07:53:30	08:47:00	09:40:30	10:34:00	11:27:30	12:21:00	13:14:30	14:08:00	15:01:30	15:55:00
Bid-offer spread	5.0%	94.5%	97.4%	94.8%	95.4%	92.5%	92.5%	92.8%	85.9%	-
Effective spread	0.3%	76.3%	98.2%	94.3%	93.7%	86.0%	74.1%	95.9%	99.7%	96.7%
Volatility	1.1%	81.0%	98.9%	96.4%	95.9%	88.6%	77.7%	99.2%	99.8%	100.0%
Price impact	0.3%	75.6%	97.6%	93.8%	92.5%	84.7%	72.8%	94.6%	98.7%	89.9%
Panel B: Excess liquidity period	**07:53:30**	**08:47:00**	**09:40:30**	**10:34:00**	**11:27:30**	**12:21:00**	**13:14:30**	**14:08:00**	**15:01:30**	**15:55:00**
Bid-offer spread	15.7%	85.3%	86.5%	86.4%	84.7%	81.7%	82.1%	81.1%	76.7%	-
Effective spread	1.8%	59.8%	70.3%	68.1%	56.2%	46.6%	34.4%	46.4%	55.6%	35.2%
Volatility	6.7%	67.7%	75.1%	74.6%	63.7%	54.6%	39.5%	53.9%	61.4%	49.1%
Price impact	1.2%	53.9%	66.4%	65.0%	53.7%	43.7%	31.5%	41.8%	48.6%	27.5%
Panel C: Negative interest rate period	**07:53:30**	**08:47:00**	**09:40:30**	**10:34:00**	**11:27:30**	**12:21:00**	**13:14:30**	**14:08:00**	**15:01:30**	**15:55:00**
Bid-offer spread	43.0%	92.1%	94.6%	97.1%	95.0%	93.5%	92.8%	92.5%	90.7%	-
Effective spread	9.0%	74.2%	87.8%	83.2%	84.2%	71.7%	63.1%	88.2%	91.8%	92.5%
Volatility	16.8%	85.7%	93.9%	86.7%	87.5%	74.9%	68.5%	93.5%	98.2%	99.6%
Price impact	9.0%	73.1%	87.8%	83.2%	84.2%	71.7%	62.7%	87.5%	91.0%	91.4%

Table 7 illustrates the availability of market liquidity indicators (in %) by intraday observations and sample periods. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008 (Panel A), the period with excess reserves ranges from 15 September 2008 to 21 January 2015 (Panel B), and the period with negative interest rates ranges from 22 January 2015 to 26 February 2016 (Panel C). The specification of the market liquidity indicators is given in Section 4.2.

Table 8: OLS regression – daily data

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	25.32***	27.93***	2.56***	12.02***
	(9.26)	(10.84)	(7.21)	(6.72)
MiRe 1d - liquidity neutral period	2.16	4.42***	0.62*	5.52**
	(1.29)	(2.63)	(1.85)	(2.12)
MiRe 2d - liquidity neutral period	3.82***	2.58***	0.30	3.25***
	(2.84)	(3.60)	(1.40)	(3.18)
MiRe 3d - liquidity neutral period	2.37**	2.49**	0.16	2.25**
	(2.00)	(2.35)	(0.97)	(2.18)
MiRe 4d - liquidity neutral period	1.40	2.16**	0.38	5.75*
	(1.15)	(2.20)	(1.56)	(1.73)
MiRe 1d - excess liquidity period	-0.17	-0.23	0.34	-0.06
	(-0.19)	(-0.23)	(1.30)	(-0.19)
MiRe 2d - excess liquidity period	1.04	0.75	0.47	-0.17
	(0.80)	(0.77)	(1.18)	(-0.51)
MiRe 3d - excess liquidity period	-0.23	-0.31	0.12	-0.10
	(-0.23)	(-0.33)	(0.59)	(-0.25)
MiRe 4d - excess liquidity period	-0.74	-0.65	-0.17	-0.21
	(-0.84)	(-0.73)	(-1.46)	(-0.55)
VIX (lag 1 day)	0.23***	0.25***	0.04***	0.17***
	(4.53)	(4.46)	(5.39)	(3.92)
Fixed-rate full allotment policy	-6.23***	-6.70***	-0.57***	-3.58***
	(-6.24)	(-6.16)	(-5.32)	(-4.68)
Ultimo: month-end	0.83	0.95	0.17	0.27
	(1.13)	(1.17)	(1.14)	(0.61)
Ultimo: quarter-end (add-on)	0.55	-0.39	0.35	0.63
	(0.41)	(-0.29)	(1.32)	(0.72)
Ultimo: year-end (add-on)	31.52	31.60	-0.33	0.67
	(1.59)	(1.57)	(-0.70)	(0.45)
MoU active quoting	-6.23***	-7.47***	-0.02	0.13
	(-5.84)	(-6.61)	(-0.26)	(0.47)
Constant	-14.06***	-18.45***	-0.51*	-0.91
	(-6.59)	(-9.09)	(-1.84)	(-0.71)
Observations	1948	1948	1948	1948
Adjusted R^2	0.35	0.37	0.33	0.38
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 8 shows the OLS regression analysis using daily data. Coefficients are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 26 February 2014. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 9: OLS regression – intraday data

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	21.84***	23.25***	2.73***	5.16***
	(15.70)	(15.85)	(10.05)	(10.95)
MiRe 1d - liquidity neutral period	3.06*	4.13***	0.78**	1.79***
	(1.94)	(2.61)	(2.21)	(3.69)
MiRe 2d - liquidity neutral period	4.32***	2.24***	0.33*	0.61**
	(3.93)	(3.59)	(1.70)	(2.24)
MiRe 3d - liquidity neutral period	2.24**	2.29**	0.15	0.50
	(2.19)	(2.34)	(0.99)	(1.30)
MiRe 4d - liquidity neutral period	1.67	1.99**	0.42*	0.46
	(1.43)	(2.06)	(1.75)	(1.01)
MiRe 1d - excess liquidity period	0.15	0.20	0.54	-0.06
	(0.13)	(0.18)	(1.42)	(-0.34)
MiRe 2d - excess liquidity period	0.80	1.24	0.77	-0.01
	(0.69)	(1.17)	(1.34)	(-0.03)
MiRe 3d - excess liquidity period	0.11	0.26	0.24	0.21
	(0.11)	(0.29)	(0.83)	(0.58)
MiRe 4d - excess liquidity period	-0.88	-0.81	-0.17	-0.09
	(-0.94)	(-1.05)	(-1.43)	(-0.48)
VIX (lag 1 day)	0.24***	0.27***	0.04***	0.11***
	(8.35)	(9.31)	(11.32)	(8.62)
Fixed-rate full allotment policy	-6.09***	-6.18***	-0.62***	-1.43***
	(-10.53)	(-10.62)	(-8.89)	(-6.76)
Ultimo: month-end	1.63*	1.46	0.25	0.35
	(1.95)	(1.55)	(1.53)	(1.56)
Ultimo: quarter-end (add-on)	-0.02	0.07	0.40	0.52
	(-0.02)	(0.05)	(1.20)	(1.01)
Ultimo: year-end (add-on)	22.19**	8.02	0.29	1.10
	(2.22)	(1.55)	(0.59)	(0.92)
MoU active quoting	-5.90***	-4.18***	0.12	0.97***
	(-12.44)	(-6.59)	(1.23)	(7.88)
time FE: 07:53:30	1.52***	-0.66	0.15	-0.24
	(2.60)	(-0.68)	(0.99)	(-1.27)
time FE: 08:47:00	0.98***	0.52*	0.42***	-0.13**
	(5.12)	(1.90)	(5.66)	(-2.02)
time FE: 09:40:30	0.09	-0.40*	0.18***	0.25***
	(0.74)	(-1.70)	(2.60)	(4.41)
time FE: 11:27:30	0.07	-0.38*	0.03	-0.14**
	(0.47)	(-1.88)	(0.41)	(-2.40)
time FE: 12:21:00	0.44**	-0.82***	-0.03	-0.37***
	(2.56)	(-3.54)	(-0.40)	(-5.38)
time FE: 13:14:30	0.72***	-0.35	-0.01	-0.55***
	(3.85)	(-1.45)	(-0.11)	(-6.08)
time FE: 14:08:00	0.52***	-0.45*	0.18**	0.05
	(2.77)	(-1.88)	(2.49)	(0.78)
time FE: 15:01:30	1.80***	-0.45**	0.76***	0.74***
	(7.09)	(-2.09)	(9.53)	(9.02)
time FE: 15:55:00		3.30***	1.69***	2.35***
		(10.18)	(13.50)	(15.81)
Constant	-14.17***	-14.82***	-1.22***	-1.04***
	(-13.97)	(-13.54)	(-5.36)	(-3.18)
Observations	14017	12202	11455	13496
Adjusted R^2	0.245	0.251	0.155	0.304
Controls	Yes	Yes	Yes	Yes
Error specification	clust. date	clust. date	clust. date	clust. date

Table 9 shows the OLS regression results using intraday market liquidity indicators. Coefficients are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Control variables are not reported. Standard errors are clustered by business day. Note that the time FE 10:34:00 is captured by the constant and that the quoted bid-offer spread cannot be calculated at the last intraday observation point (i.e. when the market closes) at 15:55:00. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively. t-statistics are in parentheses below the coefficients.

Table 10: OLS regression – VSMI index

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	22.86***	25.28***	2.19***	10.21***
	(7.95)	(9.12)	(6.18)	(5.37)
MiRe 1d - liquidity neutral period	1.84	4.08**	0.57*	5.29**
	(1.10)	(2.42)	(1.70)	(2.03)
MiRe 2d - liquidity neutral period	3.81***	2.58***	0.30	3.24***
	(2.81)	(3.40)	(1.39)	(3.13)
MiRe 3d - liquidity neutral period	2.31*	2.42**	0.15	2.20**
	(1.92)	(2.28)	(0.89)	(2.12)
MiRe 4d - liquidity neutral period	1.29	2.05**	0.36	5.67*
	(1.06)	(2.17)	(1.50)	(1.72)
MiRe 1d - excess liquidity period	-0.25	-0.33	0.33	-0.13
	(-0.28)	(-0.33)	(1.24)	(-0.39)
MiRe 2d - excess liquidity period	1.11	0.83	0.49	-0.12
	(0.85)	(0.84)	(1.20)	(-0.35)
MiRe 3d - excess liquidity period	-0.16	-0.25	0.13	-0.06
	(-0.16)	(-0.26)	(0.64)	(-0.14)
MiRe 4d - excess liquidity period	-0.60	-0.50	-0.15	-0.10
	(-0.67)	(-0.55)	(-1.27)	(-0.26)
VSMI (lag 1 day)	0.25***	0.29***	0.04***	0.19***
	(4.72)	(4.99)	(5.87)	(4.35)
Fixed-rate full allotment policy	-6.01***	-6.60***	-0.55***	-3.47***
	(-6.67)	(-6.82)	(-5.79)	(-5.02)
Ultimo: month-end	0.74	0.84	0.15	0.20
	(1.02)	(1.07)	(1.05)	(0.45)
Ultimo: quarter-end (add-on)	0.79	-0.10	0.39	0.82
	(0.59)	(-0.08)	(1.42)	(0.93)
Ultimo: year-end (add-on)	31.39	31.43	-0.36	0.56
	(1.57)	(1.54)	(-0.75)	(0.37)
MoU active quoting	-6.51***	-7.78***	-0.06	-0.08
	(-5.89)	(-6.68)	(-0.79)	(-0.28)
Constant	-13.14***	-17.78***	-0.41	-0.36
	(-6.24)	(-8.99)	(-1.58)	(-0.31)
Observations	1948	1948	1948	1948
Adjusted R^2	0.35	0.37	0.33	0.38
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 10 shows the OLS regression results with daily data using the VSMI index instead of the VIX as independent variable for the risk environment. Coefficients are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 11: OLS regression – CHF Libor-OIS spread

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	19.00***	20.77***	1.56***	7.42***
	(6.55)	(7.56)	(4.54)	(3.56)
MiRe 1d - liquidity neutral period	2.09	4.38**	0.61*	5.44**
	(1.15)	(2.41)	(1.78)	(2.03)
MiRe 2d - liquidity neutral period	4.04***	2.86***	0.34	3.38***
	(2.62)	(3.01)	(1.42)	(3.04)
MiRe 3d - liquidity neutral period	2.19	2.29*	0.13	2.11*
	(1.60)	(1.88)	(0.67)	(1.91)
MiRe 4d - liquidity neutral period	1.51	2.32**	0.40	5.80*
	(1.13)	(2.04)	(1.53)	(1.71)
MiRe 1d - excess liquidity period	-0.39	-0.50	0.30	-0.22
	(-0.47)	(-0.53)	(1.20)	(-0.75)
MiRe 2d - excess liquidity period	1.00	0.69	0.47	-0.19
	(0.79)	(0.77)	(1.18)	(-0.69)
MiRe 3d - excess liquidity period	-0.22	-0.32	0.12	-0.08
	(-0.23)	(-0.37)	(0.60)	(-0.22)
MiRe 4d - excess liquidity period	-0.48	-0.37	-0.13	-0.02
	(-0.58)	(-0.44)	(-1.13)	(-0.06)
Libor-OIS (lag 1 day)	11.40***	13.32***	1.86***	8.04***
	(6.10)	(6.98)	(8.06)	(4.58)
Fixed-rate full allotment policy	-6.55***	-7.25***	-0.65***	-3.69***
	(-7.81)	(-8.50)	(-7.68)	(-5.48)
Ultimo: month-end	0.81	0.92	0.16	0.26
	(1.19)	(1.28)	(1.17)	(0.64)
Ultimo: quarter-end (add-on)	0.79	-0.10	0.39	0.81
	(0.66)	(-0.09)	(1.50)	(0.97)
Ultimo: year-end (add-on)	31.38	31.42	-0.36	0.58
	(1.58)	(1.55)	(-0.80)	(0.42)
MoU active quoting	-6.78***	-8.10***	-0.11	-0.27
	(-6.51)	(-7.49)	(-1.38)	(-1.13)
Constant	-9.89***	-14.05***	0.11	2.34**
	(-5.03)	(-7.53)	(0.46)	(2.13)
Observations	1948	1948	1948	1948
Adjusted R^2	0.38	0.41	0.36	0.41
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 11 shows the OLS regression results with daily data using the CHF Libor-OIS spread instead of the VIX as independent variable for the risk environment. Coefficients are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 12: OLS regression – lagged dependent variable

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	11.56***	11.17***	1.64***	7.09***
	(4.97)	(4.92)	(6.17)	(6.04)
MiRe 1d - liquidity neutral period	-0.21	2.38	0.47	2.42
	(-0.12)	(1.57)	(1.48)	(1.54)
MiRe 2d - liquidity neutral period	3.10***	1.66***	0.27	2.40***
	(2.67)	(2.96)	(1.45)	(2.67)
MiRe 3d - liquidity neutral period	1.26	1.35	-0.05	0.04
	(1.23)	(1.58)	(-0.32)	(0.05)
MiRe 4d - liquidity neutral period	0.21	1.38*	0.18	3.96
	(0.21)	(1.95)	(0.70)	(1.19)
MiRe 1d - excess liquidity period	-0.56	-0.51	0.15	0.00
	(-0.92)	(-0.81)	(1.00)	(0.01)
MiRe 2d - excess liquidity period	0.88	0.88	0.39	0.08
	(0.99)	(1.35)	(1.18)	(0.25)
MiRe 3d - excess liquidity period	0.29	0.27	0.19	0.10
	(0.35)	(0.40)	(0.83)	(0.39)
MiRe 4d - excess liquidity period	0.08	-0.19	-0.10	0.22
	(0.13)	(-0.37)	(-0.99)	(0.87)
VIX (lag 1 day)	0.10***	0.10***	0.02***	0.07***
	(3.19)	(3.22)	(4.08)	(4.25)
Fixed-rate full allotment policy	-2.66***	-2.66***	-0.34***	-1.19***
	(-3.79)	(-3.85)	(-3.85)	(-4.79)
Ultimo: month-end	0.36	0.87	0.19	0.44
	(0.42)	(1.02)	(1.31)	(1.16)
Ultimo: quarter-end (add-on)	1.46	-0.04	0.31	0.10
	(1.28)	(-0.04)	(1.38)	(0.13)
Ultimo: year-end (add-on)	26.37	28.16	-0.69	-0.57
	(1.36)	(1.49)	(-1.30)	(-0.38)
MoU active quoting	-2.79***	-3.09***	-0.01	-0.05
	(-3.53)	(-3.73)	(-0.23)	(-0.40)
BOS (lag 1 time period)	0.55***			
	(7.15)			
EFF (lag 1 time period)		0.59***		
		(8.55)		
PIM (lag 1 time period)			0.37***	
			(4.51)	
VOL (lag 1 time period)				0.58***
				(10.96)
Constant	-6.14***	-7.25***	-0.31*	-1.86***
	(-4.21)	(-4.79)	(-1.80)	(-2.60)
Observations	1948	1948	1948	1948
Adjusted R^2	0.57	0.61	0.42	0.60
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 12 shows the OLS regression results with daily data using a lagged dependent variable as an explanatory variable. Coefficients are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 13: OLS regression – liquidity neutral period

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	0.34	1.03	0.42	-2.27
	(0.05)	(0.31)	(0.41)	(-0.36)
MiRe 1d - liquidity neutral period	1.56	3.55**	0.70**	5.95**
	(1.05)	(2.34)	(2.08)	(2.27)
MiRe 2d - liquidity neutral period	4.25***	2.55***	0.47**	4.43***
	(3.28)	(3.76)	(2.29)	(4.23)
MiRe 3d - liquidity neutral period	1.99*	1.86**	0.20	2.64***
	(1.89)	(2.07)	(1.27)	(2.80)
MiRe 4d - liquidity neutral period	1.11	1.73***	0.44*	6.07*
	(1.27)	(2.65)	(1.83)	(1.87)
VIX (lag 1 day)	0.13***	0.18***	0.05***	0.17**
	(2.95)	(4.43)	(5.10)	(2.57)
Ultimo: month-end	0.62	1.25	-0.04	0.54
	(0.67)	(1.59)	(-0.21)	(0.47)
Ultimo: quarter-end (add-on)	1.26	1.25	0.79*	2.17
	(0.73)	(0.65)	(1.66)	(0.92)
Ultimo: year-end (add-on)	6.16***	4.65**	0.21	2.65
	(2.83)	(2.28)	(0.34)	(1.01)
Constant	-0.55	-0.26	-0.48	0.42
	(-0.17)	(-0.09)	(-0.71)	(0.11)
Observations	614	614	614	614
Adjusted R^2	0.08	0.13	0.12	0.10
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 13 shows the OLS regression results with daily data for the liquidity neutral period. Coefficients are in bps. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 14: OLS regression – excess liquidity period

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	53.91***	56.38***	8.20***	43.87***
	(9.31)	(9.58)	(8.92)	(8.25)
MiRe 1d - excess liquidity period	0.03	-0.05	0.34	-0.03
	(0.04)	(-0.05)	(1.32)	(-0.08)
MiRe 2d - excess liquidity period	1.11	0.83	0.44	-0.33
	(0.86)	(0.87)	(1.11)	(-0.95)
MiRe 3d - excess liquidity period	-0.35	-0.45	0.07	-0.36
	(-0.33)	(-0.48)	(0.34)	(-0.92)
MiRe 4d - excess liquidity period	-0.92	-0.85	-0.24**	-0.59*
	(-1.13)	(-0.98)	(-2.11)	(-1.82)
VIX (lag 1 day)	0.22***	0.25***	0.02***	0.12***
	(4.59)	(4.76)	(4.08)	(3.91)
Fixed-rate full allotment policy	-5.04***	-5.45***	-0.32***	-2.28***
	(-5.46)	(-5.58)	(-3.84)	(-4.08)
Ultimo: month-end	1.00	0.88	0.28	0.35
	(1.04)	(0.80)	(1.59)	(1.01)
Ultimo: quarter-end (add-on)	-0.26	-1.50	0.03	-1.01
	(-0.16)	(-0.88)	(0.12)	(-1.56)
Ultimo: year-end (add-on)	45.08*	45.97*	-0.34	1.24
	(1.65)	(1.66)	(-0.84)	(1.61)
MoU active quoting	-6.01***	-7.36***	0.11	0.77**
	(-5.55)	(-6.45)	(1.15)	(2.40)
Constant	-20.26***	-25.18***	-0.84***	-3.96***
	(-9.30)	(-11.36)	(-3.12)	(-4.35)
Observations	1334	1334	1334	1334
Adjusted R^2	0.42	0.43	0.36	0.50
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 14 shows the OLS regression results with daily data for the excess liquidity period. Coefficients are in bps. The excess liquidity period lasts from 15 September 2008 to 2 May 2014. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 15: Probit regression – availability of intraday market liquidity indicators (1=available)

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
main				
Cash provider quote volume (lag 1 time period)	0.02***	0.02***	0.02***	0.03***
	(3.21)	(5.44)	(5.38)	(6.19)
Cash taker quote volume (lag 1 time period)	0.13***	0.10***	0.11***	0.02***
	(48.19)	(35.07)	(40.16)	(8.71)
Trade volume (lag 1 time period)	-0.01**	0.02***	0.01***	0.02***
	(-2.18)	(6.60)	(5.25)	(6.71)
Positioning in corridor (lag 1 day)	0.65***	-1.97***	-1.44***	-2.61***
	(3.67)	(-12.62)	(-9.63)	(-16.30)
MiRe 1d - liquidity neutral period	-0.53***	-0.41***	-0.44***	-0.23*
	(-4.48)	(-3.52)	(-3.84)	(-1.76)
MiRe 2d - liquidity neutral period	-0.31**	-0.29**	-0.46***	-0.14
	(-2.46)	(-2.33)	(-4.03)	(-1.06)
MiRe 3d - liquidity neutral period	0.16	-0.06	-0.05	-0.03
	(0.85)	(-0.36)	(-0.32)	(-0.19)
MiRe 4d - liquidity neutral period	-0.19	-0.28**	-0.33***	-0.09
	(-1.36)	(-2.10)	(-2.60)	(-0.58)
MiRe 1d - excess liquidity period	0.04	0.08	0.00	0.03
	(0.45)	(1.10)	(0.01)	(0.39)
MiRe 2d - excess liquidity period	-0.00	-0.06	-0.11	0.02
	(-0.02)	(-0.82)	(-1.59)	(0.21)
MiRe 3d - excess liquidity period	0.05	-0.03	-0.08	-0.02
	(0.64)	(-0.44)	(-1.11)	(-0.24)
MiRe 4d - excess liquidity period	0.02	0.11	0.13*	0.08
	(0.28)	(1.48)	(1.83)	(1.11)
VIX (lag 1 day)	-0.00	0.02***	0.01***	0.01***
	(-0.49)	(10.33)	(8.11)	(8.35)
Fixed-rate full allotment policy	-0.54***	0.11***	-0.06*	0.29***
	(-12.67)	(2.74)	(-1.66)	(6.64)
Ultimo: month-end	0.00	-0.14**	-0.12*	-0.11
	(0.01)	(-2.13)	(-1.78)	(-1.54)
Ultimo: quarter-end (add-on)	0.01	0.16	0.22*	0.13
	(0.07)	(1.29)	(1.74)	(0.99)
Ultimo: year-end (add-on)	-0.73***	-0.20	-0.10	-0.25
	(-3.08)	(-0.91)	(-0.47)	(-1.16)
MoU active quoting	0.48***	-0.14***	-0.15***	-0.21***
	(6.27)	(-2.98)	(-3.13)	(-4.34)
Constant	-7.22	2.45***	1.88***	3.41***
	(-0.06)	(20.98)	(16.73)	(27.96)
Observations	20340	20340	20340	20340
Time FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Pseudo R-squared	.58	.45	.43	.45

Table 15 shows the probit regression results, explaining the availability of intraday market liquidity indicators. The dependent variables are binary indicators, which take the value one if a market liquidity indicator is available at time *t* and zero otherwise. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Time-of-day fixed effects and control variables are not reported. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively. t-statistics are in parentheses below the coefficients.

Table 16: Heckman regression

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
main				
Positioning in corridor (lag 1 day)	21.94***	18.24***	2.53***	3.79***
MiRe 1d - liquidity neutral period	2.95***	3.20***	0.73***	1.66***
MiRe 2d - liquidity neutral period	4.26***	1.56**	0.28	0.52**
MiRe 3d - liquidity neutral period	2.26***	2.08***	0.14	0.46*
MiRe 4d - liquidity neutral period	1.61**	1.42**	0.39**	0.40
MiRe 1d - excess liquidity period	0.14	0.25	0.54***	-0.05
MiRe 2d - excess liquidity period	0.78*	1.08**	0.75***	-0.00
MiRe 3d - excess liquidity period	0.12	0.16	0.24	0.22
MiRe 4d - excess liquidity period	-0.89**	-0.53	-0.16	-0.02
VIX (lag 1 day)	0.24***	0.29***	0.04***	0.11***
Fixed-rate full allotment policy	-6.32***	-6.13***	-0.64***	-1.25***
Ultimo: month-end	1.65***	1.36***	0.25**	0.32**
Ultimo: quarter-end (add-on)	-0.03	0.34	0.41*	0.58**
Ultimo: year-end (add-on)	21.92***	7.20***	0.26	0.95*
MoU active quoting	-5.83***	-5.02***	0.09	0.65***
Constant	-13.10***	-7.37***	0.63***	2.46***
select				
Cash provider quote volume (lag 1 time period)	0.02***	0.03***	0.02***	0.03***
Cash taker quote volume (lag 1 time period)	0.13***	0.10***	0.11***	0.02***
Trade volume (lag 1 time period)	-0.01***	0.01***	0.01***	0.01***
Positioning in corridor (lag 1 day)	0.25	-1.97***	-1.45***	-2.61***
MiRe 1d - liquidity neutral period	-0.37***	-0.42***	-0.44***	-0.23*
MiRe 2d - liquidity neutral period	-0.18	-0.29**	-0.46***	-0.14
MiRe 3d - liquidity neutral period	0.10	-0.06	-0.04	-0.03
MiRe 4d - liquidity neutral period	-0.11	-0.27**	-0.33***	-0.08
MiRe 1d - excess liquidity period	0.04	0.08	0.00	0.03
MiRe 2d - excess liquidity period	-0.01	-0.06	-0.11	0.01
MiRe 3d - excess liquidity period	0.05	-0.03	-0.08	-0.02
MiRe 4d - excess liquidity period	0.01	0.11	0.13*	0.08
VIX (lag 1 day)	-0.00	0.02***	0.01***	0.01***
Fixed-rate full allotment policy	-0.43***	0.12***	-0.05	0.29***
Ultimo: month-end	-0.01	-0.14**	-0.12*	-0.11
Ultimo: quarter-end (add-on)	0.01	0.17	0.22*	0.13
Ultimo: year-end (add-on)	-0.66***	-0.20	-0.10	-0.25
MoU active quoting	0.24***	-0.14***	-0.15***	-0.21***
Constant	-0.75***	2.74***	2.21***	3.61***
mills				
lambda	0.78**	5.08***	0.23**	1.26***
Observations	20340	20340	20340	20340
Time FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes

Table 16 reports the regression results for the Heckman selection regression using intraday market liquidity indicators. The upper panel shows the regression coefficients for the main regression model while the lower panel reports the regression coefficients for the selection equation. The selection equation controls for not observing a market liquidity indicator. Coefficients in the main equation are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Time-of-day fixed effects and control variables are not reported. The Heckman regression is estimated using the two-step procedure, which provides efficient estimates of the parameters (see Cameron and Trivedi (2005)) and standard errors are calculated based on the two-step variance estimator derived by Heckman. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

A.3 Principal component analysis (PCA)

The positive correlation coefficients between the different liquidity measures indicate that they might all be determined by the same underlying driver of liquidity. To extract the common factor from the different market liquidity indicators, I conduct a PCA. With the PCA, the number of liquidity indicators might be reduced with only a few factors remaining that explain the variance of the different liquidity indicators. For the PCA, only the first eigenvalue is larger than the unit, which, however, explains approximately 55% of the total variance. The second and third components have still relatively high eigenvalues of 0.82 and 0.76, respectively. The explanatory power of the first three principal components for the individual liquidity measures can be demonstrated if market liquidity indicators are regressed on the corresponding principal components. Table 17 illustrates the adjusted-R^2 and highlights that the first three principal components explain between 58% and 87% of the variation in market liquidity indicators.

Table 17: Common liquidity factor

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Principal component: 1	4.979***	4.902***	0.807***	1.262***
	(120.30)	(112.74)	(171.32)	(126.12)
Principal component: 2	-2.311***	-4.396***	1.506***	0.894***
	(-34.57)	(-62.61)	(197.84)	(55.32)
Principal component: 3	-2.804***	0.198***	-0.846***	2.517***
	(-40.28)	(2.71)	(-106.78)	(149.52)
Adjusted R^2	0.590	0.581	0.869	0.775

Table 17 shows the regression results when regressing liquidity indicators on the first three principal components. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). The sample period ranges from 3 April 2006 to 26 February 2016. Huber-White corrected standard errors are used. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively. t-statistics are in parentheses below the coefficients.

Appendix I

Re-Use of Collateral in the Repo Market*

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Abstract

This paper introduces a methodology to estimate the re-use of collateral based on actual transaction data. With a comprehensive dataset from the Swiss franc repo market we are able to provide the first systematic study on the re-use of collateral. We find that re-using collateral was most popular prior to the financial crisis when roughly 10% of the outstanding interbank volume was secured with re-used collateral. Furthermore, we show that the re-use of collateral increases with the scarcity of collateral. By giving an estimate of the collateral re-use and explaining its drivers, the paper contributes to the on-going debate on collateral availability.

JEL Classification: D47, E58, G01, G18, G21, G32
Keywords: Re-use of collateral, repo, money market, financial stability, Switzerland.

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1 Introduction

Up to now, central banks and regulators have lacked evidence on the re-use of collateral, although this issue has been at the top of regulators' policy agenda (Financial Stability Board, 2012a). Especially, the re-use of collateral has yet not been estimated and analysed based on actual transaction data.

This paper aims to address this issue. First, we estimate the re-use activity in an interbank repo market by developing an algorithm which identifies re-used collateral based on actual transaction data. Second, we analyse the drivers of collateral re-use. We focus on the availability of securities, as re-using collateral allows banks to conduct transactions regardless of a potential collateral constraint (i.e. we test whether collateral re-use is a form of collateral optimisation). Analysing this relationship is of particular interest because current regulatory initiatives have caused an intense debate on collateral availability (see, for example, Levels and Capel (2012) and Committee on the Global Financial System (2013)).

The Swiss franc (CHF) repo market qualifies for a thorough analysis of the re-use of collateral as the re-use is not restricted, neither technically, legally nor economically. Having a comprehensive dataset from the CHF interbank repo market at our disposal allows us, for the first time, to estimate and analyse the re-use of collateral by considering individual transactions. Additionally, the dataset spanning from March 2006 to February 2013 enables us to analyse the re-use for different time periods such as before, during and after the financial crisis.

Our findings can be summarised as follows. Market participants in the CHF repo market re-use collateral. The re-use activity remained relatively constant until mid-2007 when roughly 10% of the outstanding volume was secured with re-used collateral. Afterwards, it increased and reached its highest level in autumn 2007, at almost 20%. In 2008, the re-use activity suddenly declined to very low levels and remained there afterwards. The collateral re-used typically originates from a long-term repo (one month and longer) and is used in a short-term transaction.

Based on a logit regression model the drivers of collateral re-use are assessed. The regression results reveal that the re-use of collateral increases with the scarcity of collateral, i.e. it decreases when the collateral availability increases. This goes along with the evidence that the re-use in the interbank market is positively related with the general securities borrowing activity of banks. Hence, banks simultaneously re-use collateral in the interbank market and borrow securities from clients. Furthermore, there is evidence for a significant impact of the maturity of the transaction on the re-use probability. Banks re-use collateral if they lend cash long-term and borrow cash short-term. This allows them to keep a relatively small pool of securities when, for example, playing the yield curve.

Overall, the extent of re-use within the CHF repo market segment is rather low compared to the findings by Singh (2011) and Aitken and Singh (2009) that calculate the rehypothecation by large global banks. This is due to the fact that in contrast to these authors, we only evaluate the re-use in CHF repo transactions, i.e. a specific market segment and currency.[1] Thus, by the definition of our dataset the overall re-use in the banking system cannot be captured and the re-use measured is clearly lower than the overall re-use. However, in this study the re-use activity is for the first time calculated based on actual transaction data which allows to gain a detailed understanding of the determinants of the re-use activity. These determinants are expected to hold also in other market segments and currency areas. Furthermore, the proposed methodology to estimate the re-use of collateral could be applied to data stemming from trade repositories.

Our findings have important implications for policy makers, regulators and central banks. The measure presented for the re-use of collateral can be used as an indicator for collateral scarcity and financial stress. By explaining the drivers and determinants of collateral re-use, we further create a solid foundation for a discussion about financial stability concerns and market efficiency related to the re-use of collateral. We also show that if collateral scarcity increases, banks will have an incentive to re-use collateral, which in turn increases the leverage and the interconnectedness in financial markets. In the light of stricter standards for over-the-counter derivatives or the liquidity coverage ratio, regulators have to consider that these regulatory initiatives might increase collateral scarcity and, according to our findings, the re-use of collateral.

This paper is related to the literature on rehypothecation and re-use of collateral as well as to the broader literature on repo markets. With the experience of the financial crisis, analysing the market for liquidity and especially the repo market is of first order relevance (Fecht, Nyborg and Rocholl, 2011). Theoretical and empirical literature has documented and dealt with the important role of margin requirements, fire sales and potential rollover risks (e.g. Gorton and Metrick (2012, 2010a,b), Brunnermeier and Pedersen (2009), He and Xiong (2012) as well as Hördahl and King (2008)). Moreover, empirical studies of the structure of repo markets were provided for example by Copeland, Martin and Walker (2011) for the US tri-party, by Mancini, Ranaldo and Wrampelmeyer (2013) as well as Bindseil, Nyborg and Strebulaev (2009) for the Eurozone and by Kraenzlin (2007) for the CHF repo market. In contrast, literature on the re-use of collateral is rare. Related studies are Aitken and Singh (2009) and Singh (2011) which have, however, estimated the magnitude of collateral rehypothecation. They find evidence for a considerable amount of rehypothecation prior to the financial crisis and a rapid decline after Lehman's bankruptcy. In this regard, it is important to note that the terms re-use and rehypothecation have, even though sometimes used interchangeably, distinct meanings (Singh, 2014). The Financial Stability Board (2012b) defines rehypothecation as "the right by financial intermediaries to sell, pledge, invest or perform transactions with client assets they hold" and

[1] Collateral could, for example, also originate from a CHF repo transaction and then be re-used in a EUR repo transaction (on the same trading platform).

the re-use of collateral as "securities delivered in one transaction [that] are used to collateralise another transaction". Put differently, rehypothecation refers to the use of client assets by banks in their own funding and is particularly popular in investment banks' prime brokerage services. The term re-use is used more broadly and refers generally to any use of collateral received in another transaction (Singh, 2014). In a repo transaction, the right to re-use securities arises automatically (if they are conducted under a title-transfer arrangement) and does not need to be explicitly granted by the collateral provider. In this paper, we solely analyze the re-use of collateral within the repo market.

The remainder of this paper is structured as follows. Section 2 provides an overview of the institutional setup of the CHF repo market, while in Section 3 the algorithm to determine repo transactions with a collateral re-use is explained. Section 4 discusses stylised facts about the re-use activity. Section 5 applies an econometric analysis to evaluate the factors determining collateral re-use. Finally, Section 6 concludes.

2 Institutional setup

2.1 Characteristics of the CHF repo market

Until April 2014, CHF interbank repo transactions in Switzerland were mostly traded on the Eurex Repo trading platform, which was launched in 1999 (Kraenzlin and von Scarpatetti, 2011).[2] The trading platform was set up as a non-anonymous market with bilateral trade relationships. The clearing and settlement systems and the trading platform together constitute the Swiss value chain - an infrastructure that allows the complete electronic integration of trading, clearing and settlement. The settlement is thereby based on the delivery versus payment mechanism and takes place in central bank money on the real-time gross settlement system for CHF - the Swiss Interbank Clearing (SIC) - and on the Swiss securities settlement system (SECOM).

To obtain access to the CHF repo market, the participants must have a SIC settlement account, which requires a sight deposit account at the SNB. Consequently, the number of participants in the CHF repo market depends on the access policy of the SNB. Compared to other central banks, the SNB has followed a liberal access policy (Kraenzlin and Nellen, 2015). Beside banks domiciled in Switzerland, banks domiciled abroad and certain non-banks (domestic insurance companies) are eligible for a sight deposit account at the SNB (Swiss National Bank, 2010). The liberal access policy of the SNB contributed to the steady increase in the number of participants in the CHF repo market - from 37 in 1999 to more than 170 in 2011. Similarly, the outstanding volume in the interbank repo market also increased significantly. It reached its peak in September 2008 after the collapse of Lehman Brothers. At that time, the outstanding volume was about CHF 74 billion (bn).

[2] As of 1 May 2014 interbank repo transactions are mostly conducted on the new SIX Repo trading platform.

2.2 Collateral standards in the interbank market

In the CHF repo market, almost all interbank repo transactions (more than 99%) are traded against a collateral basket (i.e. general collateral repos).[3] In more than 95% of all CHF interbank repo transactions the collateral basket, which is defined by the SNB (SNB GC basket) for its monetary policy operations, is used. Compared to other central banks, the SNB's collateral framework is liberal regarding eligible currencies but restrictive concerning the quality of the securities (Kraenzlin and Nellen, 2015).[4] The SNB GC basket currently contains about 2,700 different securities worth CHF 9,500 bn. As the SNB GC basket is subject to daily modifications (i.e. due to new issues, redemptions and exclusions), smaller fluctuations in the size of the basket occur.

One of the main differences between the CHF repo market and other repo markets is the absence of haircuts in the former. This means that irrespective of the characteristics of the collateral delivered (e.g. asset type or currency of denomination), the cash amount is always covered by a security position with an identical market value.

2.3 The legal, technical and economic setup for re-use

The Swiss framework agreement on repo transactions and the PSA/ISMA global master repurchase agreement (GMRA) with Swiss annex form the legal basis for any repo transaction in the CHF repo market (Swiss National Bank, 2004). Both agreements state that with the transfer of collateral the parties transfer the full and unencumbered legal ownership of the security. Securities transferred in a repo are thus free of any rights of third parties. Additionally, in standard repo contracts the parties typically agree not to grant the right of substitution. Early termination is theoretically possible but not allowed in most standard contracts (Swiss Bankers Association, 1999). The re-use of securities in the CHF interbank market is therefore not restricted by any legal aspects. Further, the re-use of collateral is technically feasible in the securities settlement system (see Appendix for a detailed description).

From an economic point of view, a collateral re-use can only occur if the cash taker has outstanding volume as a cash provider (i.e. received collateral) at the same time. As the CHF repo market is a market with bilateral trade relationships, one can expect two groups of institutions to re-use collateral: market makers and institutions that regularly lend cash long-term and refinance themselves short-term. While in the former case the re-use is typically conducted in the same maturities, the re-use in the latter is rather done in overnight, tom-next or spot-next maturities (i.e. day-to-day maturities). In both cases it is rational to assume that

[3] The main motivation for a general collateral repo is to get cash and not a specific security, whereas the cash provider's interest is to lend without counterparty risks (Bank of England, 2012).

[4] The minimum credit rating for eligible securities is AA- (A) for securities denominated in foreign currencies (in CHF). The minimum liquidity requirement is an issuance volume of at least CHF 1 bn (CHF 0.1 bn) for securities denominated in foreign currencies (in CHF). Eligible securities can be denominated in CHF, EUR, USD, GBP, DKK, SEK and NOK (Swiss National Bank, 2007).

banks might re-use collateral to reduce their own funding collateral needs (own securities used).

2.4 The bank's pool of securities

The availability of securities plays a crucial role for banks, especially in the secured money market. Without re-use, a given pool of available securities constrains the maximum possible turnover in the repo market, thus hampering the efficient allocation of liquidity.[5]

Table 1 shows the securities holdings of banks domiciled in Switzerland. By the end of 2012, Swiss banks held a stock of securities worth CHF 262 bn (9.4% of the total balance sheet) in trading portfolios and as a financial investment. Prior to the financial crisis, banks held roughly the double, worth CHF 555 bn (17.4% of the total balance sheet).

The share of securities holdings that are eligible for SNB repos increased from about 12% to about 45% in 2010 but decreased again in 2011 and 2012.[6] A significant share of SNB eligible securities was held in the custody cover account "SNB" for the liquidity-shortage financing facility (LSFF) and was consequently not available for interbank repos as they can only be used for the standing facility (Swiss National Bank, 2008). Taking the LSFF holdings into account, the securities available for CHF interbank repos fluctuate between CHF 50 bn and CHF 108 bn.

3 Methodology

To estimate the re-use of collateral in the CHF repo market, we use transaction data from the Eurex Repo trading platform and the corresponding collateral information from SECOM ranging from 1 March 2006 until 28 February 2013. Only the combination of these two datasets allows an analysis of the re-use of collateral. The repo dataset includes for each transaction the transaction ID, cash taker ID, cash provider ID, purchase date, repurchase date and collateral basket. The collateral dataset includes the transaction ID, the International Securities Identification Number (ISIN) of delivered collateral and the respective market value. The transaction ID links the repo dataset with the collateral dataset.

A repo transaction can be secured with several securities. In our sample, on average about three securities have been used to secure one repo transaction. We analyse these collateral transactions in the following. For this reason, statistics are reported in terms of collateral transactions rather than repo transactions.

To identify collateral transactions with re-used collateral we developed an identification algorithm that was written in MATLAB and works as follows. First, the algorithm sorts the dataset by purchase date (in ascending order) and duration of the repo transaction (in descending order), i.e. starting with the oldest purchase date and the longest duration. Second, for each collateral

[5] Since the outbreak of the financial crisis banks have significantly shifted their exposures from unsecured to secured markets, which consequently increased the demand for collateral (Guggenheim et al., 2011).

[6] This increase might have been in part due to the SNB's issuance of own debt register claims (SNB Bills in CHF and USD) from 2008 until 2011, which are part of the SNB GC basket.

transaction (i.e. each entry in the dataset) the algorithm iterates over all subsequent transaction included in the dataset and checks whether the following conditions hold cumulatively:

- identical securities (i.e. ISINs) are used in both transactions;
- the collateral provider in the second transaction is the same as the collateral taker in the first transaction;
- the repurchase date of the second transaction is not later than the repurchase date of the first transaction.

If these three conditions are fulfilled, the first repo transaction is flagged as a possible "initial transaction" and the second one as a possible "re-use transaction". In the last step, the algorithm reduces the probability of overestimation.[7] A transaction can be the initial transaction of several re-use transactions. However, as soon as the collateral value of the initial transaction is used up by re-use transactions, possible subsequent re-use transactions are no longer flagged as re-use transactions.[8]

The algorithm underestimates the re-use of collateral at the beginning of the observation period, as we do not observe initial transactions before the starting date of the dataset, i.e. before 1 March 2006. With maturities of repo transactions of up to one year, there is a potential underestimation of the re-use during the first twelve months. That is, the identified re-use is potentially underestimated until the end of February 2007. As 97.5% of all transactions have a maturity of up to three months, the underestimation is expected to be substantial only during the first three months of the dataset.[9] Therefore, we exclude the period ranging from 1 March until 31 May 2006 from the analysis and conduct the descriptive statistics and the regression analysis from 1 June 2006 onwards.[10]

4 Stylised facts about re-use activity

4.1 Descriptive statistics

The analysed period lasts from 1 June 2006 until 28 February 2013 containing 161,108 repo transactions and 470,823 collateral transactions. During the sample period, repo transactions worth about CHF 11.6 tn were settled. Overall, 162 different institutions were active in at least one transaction. On an average trading day roughly 240 (before September 2008), respectively 140 (after September 2008) different ISINs have been used.[11]

[7] The fungibility of ISINs and the necessity of the repurchase condition are discussed in the appendix.
[8] The algorithm does not flag a re-use due to a too low initial value in 10% of the matches.
[9] The potential underestimation is described in detail in the online appendix.
[10] Several robustness checks collected in the online appendix confirm that the regression analysis (Section 5) is robust to the choice of the starting date.
[11] See also Figure 3 in the online appendix, which indicates that there are no security-specific re-use effects.

Of the 470,823 collateral transactions, 246,271 transactions were performed by cash takers who had an outstanding volume as cash provider at the same time. Note that only those transactions could be secured with re-used collateral. Having applied the methodology described in the previous section, we identified 21,370 collateral transactions (4.5% of all transactions) serving as initial transactions for at least one re-use. Moreover, we identified 87,503 re-use transactions (18.6% of all transactions). This implies that the collateral from one initial transaction was re-used on average four times (see Table 2).

As illustrated in Figure 1, re-use transactions contributed on average to about CHF 2.2 bn of the total outstanding volume of CHF 33.9 bn. 73 market participants re-used collateral in at least one transaction, whereas the most active five market participants contributed to 31% of all re-use transactions.

Table 3 shows that the typical re-use occurs with collateral originating from a rather long-term repo (1M-3M maturities) that is re-used in a short-term repo. In other words, the probability of re-use increases with the duration of the initial transaction. Especially, for transactions with a maturity of three months and more the re-use probability increases significantly. Irrespective of the maturity of the initial repo, most of the collateral, i.e. 84%, is re-used in day-to-day repo transactions.

4.2 Measures of collateral re-use

To describe the magnitude of collateral re-use, different measures have been used so far in the literature. In this paper two measures to describe the re-use of collateral are presented: the re-use rate and the collateral multiplier.

The re-use rate is a measure used by Bottazzi, Luque and Páscoa (2012) and is defined as the ratio of the market value of the re-used securities to the overall market activity. The re-use rate (rr) is a value in the interval $[0, 1)$, where a value of zero would imply no re-use at all and a value arbitrarily close to one would imply an almost infinite re-use. Hence, the re-use rate is a relative measure of the re-use activity in a repo market. This measure can be applied to the overall market as well as to individual institutions.[12] The re-use rate at time t is defined as follows:

$$rr_t = \frac{\sum_{n=1}^{N} d_n c_{n,t}}{\sum_{n=1}^{N} c_{n,t}} \tag{1}$$

where $c_{n,t}$ denotes the value of collateral n of an outstanding repo at time t. To account for the re-use of collateral, a dummy variable d_n is included, which is equal to one if the collateral is re-used and zero otherwise.

The re-use rate does not consider the overall pool of eligible securities and therefore does

[12] In contrast to the overall re-use rate, the individual re-use rate is a value in the interval $[0, 1]$ as theoretically every cash taking transaction of a market participant can be secured with re-used collateral.

not give an indication of the impact of the re-use on the overall pool. To account for the availability of securities, the collateral multiplier can be adopted from its famous pendant, the money multiplier. For this paper, the collateral multiplier (m) is defined as 1 plus the ratio of re-used collateral divided by the available pool of securities. It is thus a value in the interval $[1, \infty)$ and defined as follows:

$$m_t = 1 + \frac{\sum_{n=1}^{N} d_n c_{n,t}}{\sum_{i=1}^{I} s_{i,t}} \tag{2}$$

where $s_{i,t}$ is the market value of the available securities (i) eligible for repos at time t (i.e. SNB-eligible securities available). For example, a re-use of securities worth CHF 5 bn and a pool of eligible securities amounting to CHF 10 bn would imply a collateral multiplier of 1.5. The collateral multiplier thus links the re-use to the overall availability of securities, whereas the re-use rate is a measure of the frequency of collateral re-use within the overall market.

4.3 Re-use rate and collateral multiplier over time

Figure 2 shows the development of the re-use rate over time. On average, the re-use rate was about 0.05. In other words, 5% of the outstanding volume was secured with re-used collateral. The re-use rate remained relatively constant until mid-2007, at about 0.075 to 0.125. Afterwards, it increased and reached its highest level in autumn 2007, at about 0.2. In 2008, the re-use rate suddenly declined to a level of roughly 0.02 and remained unchanged afterwards. The collateral multiplier shows a similar pattern (see Figure 3). The collateral multiplier also spiked in autumn 2007, especially when the available collateral suddenly dropped. It reached its maximum value of almost 1.2 in the third quarter of 2007 indicating a relative shortage of collateral. Afterwards, the collateral multiplier shows a similar picture as the re-use rate, even though the available pool of collateral decreased remarkably in 2011.

Both measures reached their highest value in 2007, i.e. before the outstanding volume of the CHF repo market peaked and prior to the outbreak of the financial crisis. During this period, the banks' pool of available securities decreased twice (see Figure 3). Therefore, the increasing re-use activity might have been due to collateral constraints of certain banks that were consequently forced to re-use collateral. Furthermore, it is worth mentioning that the re-use activity remained very low after 2009, even though the pool of available securities declined to its lowest level in the observation period. This might be due to the very low trading activity or also due to a structural change in the market. Prior to 2009, market participants acting as cash provider and cash taker were prevalent. After the financial crisis, this share dropped significantly. For example, in August 2011, only 74% of the outstanding volume was due to market participants who had outstanding volume as cash taker and provider, whereas this share was about 97% prior to 2009.

4.4 Individual re-use rates

The re-use of collateral might be driven by the re-use activity of individual banks. A higher re-use activity might indicate a very active collateral management, or even (temporary) collateral constraints of certain market participants. In order to evaluate the re-use activity of different banks, the re-use rates of individual banks are computed. The results reveal that banks re-use collateral at remarkably different rates (see Figure 2 in the online appendix).[13] One market participant has an average individual re-use rate of close to 1. Another six banks have an average re-use rate of more than 0.5. Overall, about 30 banks have an average re-use rate of above 0.1. Inspecting banks' re-use rates as well as their overall market activity reveals the following facts. On the one hand, the re-use activity of banks is neither increasing in their outstanding volume as cash providers nor as cash takers. On the other hand, small institutions that predominantly lend cash re-use heavily when they exceptionally act as cash taker. Banks with the highest re-use rates act most of the time as cash providers (more than 70% of their trades).

5 Determinants of re-use

In the following we evaluate the determinants of collateral re-use. The re-use can be seen as a binary decision: either a collateral transaction is covered with a re-used security or not. Thus, we estimate a binary response model. We therefore analyse by what factors the re-use of collateral is influenced and not how much in value is re-used.[14] In the following subsections, we motivate our hypotheses, describe the modifications to the dataset, specify our regression model and discuss the regression results.

5.1 Hypotheses

Without re-use of collateral, the market activity in the CHF repo market is constrained by the pool of available securities. The re-use of collateral reduces this constraint. In other words, a reduction in the availability of securities will ceteris paribus require the re-use of collateral to increase, given a specific outstanding volume. Levels and Capel (2012) thus argue that the re-use of collateral is a special form of collateral optimisation. Hence, we expect an increasing pool of available securities to have a negative impact on the re-use activity. The availability of securities is measured by the market value of all available (SNB eligible) securities, reported on a quarterly basis by FINMA regulated banks (i.e. banks domiciled in Switzerland).

Hypothesis 1: An increasing pool of available securities reduces the probability of a re-use.

[13] Of the 162 market participants, 102 would have been able to re-use collateral as they were active as cash taker and cash provider at the same time.

[14] The value of a collateral transaction depends on the face value of the underlying security. Thus, a censored normal regression model would not be appropriate to model the decision to re-use collateral.

The re-use activity in the interbank market might also be determined by the securities borrowing activity of banks from clients' accounts (SNB eligible and non-SNB eligible).[15] Hence, we include securities borrowing from clients' accounts in the analysis. We expect the re-use of collateral to increase if the securities borrowing activity increases. In other words, banks simultaneously re-use collateral and borrow securities from clients' accounts in times of high collateral scarcity. Note that securities borrowing is also determined by the pool of available securities. We consider this fact in the regression analysis by orthogonalising the securities borrowing variable (see Section 5.3).

Hypothesis 2: The re-use of collateral increases with the securities borrowing activity.

Monnet (2011) argues that "rehypothecation lowers traders' funding liquidity needs [or stress], the ease with which a trader can obtain funding". This argument also applies for re-use of collateral. In interbank repo markets, banks often lend cash long-term and refinance themselves short-term. Re-using collateral in those transactions would reduce bank's collateral needs (the own securities used) and thereby increase overall market liquidity (Brunnermeier and Pedersen, 2009). Accordingly, the re-use of collateral is especially valuable for banks in short-term refinancing operations. Put differently, the re-use of collateral facilitates playing the yield curve and allows banks to keep their pool of own securities relatively small, which reduces transaction costs. To empirically test this hypothesis, we include the share of outstanding long-term transactions (i.e. with a term longer than one month) as well as the duration of the transaction as independent variables. On the one hand, we expect a positive relationship between the share of outstanding long-term transactions and the probability of re-use. On the other hand, the re-use probability is expected to be higher if the duration of a repo transaction is shorter.

Hypothesis 3: The re-use of collateral is especially popular for banks when lending cash long-term and borrowing cash short-term.

Singh and Aitken (2010) show that rehypothecation has significantly decreased with the intensification of the financial crisis, as market participants became more and more risk-averse. If market participants in the CHF repo market were to associate risk with the re-use of collateral, one could expect a negative relation between stress in the CHF money market and the re-use of collateral. To account for money market stress, the credit risk premium, measured by the spread between the unsecured and the secured interest rate for CHF liquidity in the tom-next maturity (TOIS-fixing minus SARTN) is included in the analysis.

[15] In 2009, FINMA introduced a new legislation concerning SLB transactions, which resulted in a significant decline of securities borrowing from clients' accounts (see Table 1).

Hypothesis 4: The re-use activity decreases with money market stress.

Empirical and theoretical research has shown that the relationship between two market participants significantly impacts trading conditions (see, for example, Furfine (1990)). Recently, Duffie (2013) presented evidence that during the financial crisis prime-brokerage clients (collateral providers) made sure that the securities they held in their custodies were not rehypothecated by their broker-dealers. Theoretical models by Infante (2014) and Eren (2014) predict this behaviour and show that a collateral provider might have an incentive to withdraw securities during crisis periods. Based on these models, one might also expect that the relationship between two market participants in the CHF repo market influences the re-use of collateral. Collateral providers that re-use collateral might be concerned about not receiving back the collateral which they have to return to the initial collateral provider. This risk amplifies with a weak diversification of the re-using counterparty. In the regression we thus control for the diversification of the collateral provider, which is measured by the sum of cash taking transactions with the corresponding cash provider to the total sum of cash taker transactions. Thus, the measure for relationship is a value in the interval $(0, 1]$. A very low value characterises a relatively low exposure to this counterparty, whereas a value close to one indicates a very large exposure. We expect a high relationship ratio to reduce the probability of a re-use of collateral.

Hypothesis 5: Weakly diversified collateral providers re-use less collateral than well diversified collateral providers.

5.2 Control variables

As the CHF repo market is set up as a market with bilateral trade relationships, counterparties might also negotiate about the specific collateral delivered. According to Ewerhart and Tapking (2008), counterparties in bilateral markets prefer to use high-quality collateral in the interbank market in order to balance the counterparties' risk exposure as efficiently as possible. Therefore, they might have an incentive to deliver, and especially to re-use, good rather than bad collateral. Consequently, the credit rating of the corresponding security is taken into account.[16]

As Swiss banks have to fulfil minimum reserve requirements, one might expect that they also re-use collateral to fulfil these requirements (at least in the short run, just prior to the end of the maintenance period). Thus, we control for the individual liquidity position of market participants by including the daily gross excess reserve of a bank in analogy to Fecht, Nyborg and Rocholl (2011).

Furthermore, we account for the overall outstanding volume in the CHF repo market. A

[16]We consider the best security credit rating from Standard & Poor's, Moody's or Fitch.

higher outstanding volume might imply an increasing need for collateral re-use. Moreover, the re-use of securities might be conducted by market makers who are active as cash taker and cash provider in the same maturities on the same day. We therefore include a dummy variable indicating whether a market maker was involved in the transaction.

5.3 Data

For the binary response model below, the dataset is adjusted as follows. To exclude the period with very high excess liquidity and very low trading activity, we reduce the sample to the time period between 1 June 2006 and 2 August 2011 reducing the number of collateral transactions to 426,042.[17] Furthermore, only transactions, where the cash taker has outstanding cash provider repos at the same time are involved, as those participants are the only ones, which are able to re-use collateral. This shrinks the sample to 237,094 transactions. Additionally, 852 transactions are excluded due to missing observations in the money market stress variable.[18] Finally, 2,242 transactions of banks, which do not exhibit a re-use of collateral are not considered in the dataset. The final dataset contains 234,000 transactions.

The descriptive statistics of the variables can be found in Table 4. Overall, in 36% of the collateral transactions a re-use of collateral is observed. This probability is higher than indicated by the re-use rate due to two reasons. First, the dataset includes only transactions where the cash taker also has an outstanding volume as cash provider. Second, short-term transactions do not contribute as strongly to the re-use rate as longer-term transactions do. For variables in cash amounts we employ the natural log, if they are strictly positive. For variables with observation frequencies lower than daily, the last available observation is used.

The securities borrowing variable is closely related to the available securities variable. The correlation coefficient between these two variables is -0.85 (see online appendix). To avoid a potential multicollinearity problem in our regression analysis we orthogonalise the securities borrowing variable (see Equation 3 and Table 4 for abbreviations) with respect to the available securities variable. The orthogonalised variable (η) is denoted as securities borrowing (orth.). The correlation between the securities borrowing (orth.) and the original securities borrowing variable is 0.53, showing that the orthogonalised variable qualifies as a valid measure for securities borrowing.

$$SB_i = \beta_1 + \beta_2 AP_i + \eta_i \tag{3}$$

[17]On 3 August 2011 the SNB increased the supply of liquidity as a measure against strong CHF. Consequently, the trading activity decreased significantly. As mentioned in Section 3 the re-use is potentially underestimated between June 2006 and February 2007. Several robustness checks collected in the online appendix confirm that our regression results are not affected by the potential underestimation. For more details, see online appendix.

[18]On the following days the SARTN rate was not available: 29 December 2006, 27 December 2007, 31 December 2008 and 28 October 2009.

5.4 Binary response model

To determine the re-use of collateral, we use a logit model with clustered standard errors.[19] We regress the dummy variable collateral re-use (indicating whether a security has been re-used or not) on the variables specified above. Equation 4 and 5 show our regression specifications (see Table 4 for abbreviations).

$$Pr[y_i = 1|\boldsymbol{x}_i] = \frac{exp(\boldsymbol{x}_i'\boldsymbol{\theta})}{1 + exp(\boldsymbol{x}_i'\boldsymbol{\theta})} \tag{4}$$

$$\begin{aligned} \boldsymbol{x}_i'\boldsymbol{\theta} = \beta_1 + \beta_2 SB_i + \beta_3 AP_i + \beta_4 RE_i + \sum_{j=1}^{J-1} \delta_j RA_{i,j} + \beta_5 MS_i + \beta_6 GE_i \\ + \beta_7 MM_i + \beta_8 OV_i + \beta_9 DU_i + \beta_{10} VA_i + \beta_{11} LT_i + \sum_{n=1}^{N-1} \gamma_n d_{i,n} \end{aligned} \tag{5}$$

$RA_{i,j}$ dummy variable = 1 if credit rating j was used in transaction i, else 0. J represents the credit rating categories AAA, AA+, AA, AA-, A+, A and no credit rating;

$d_{i,n}$ dummy variable = 1 if bank n was involved in transaction i, else 0.

We control for bank-specific effects by using dummy variables for $N-1$ cash takers.[20] As for small market participants only periodical observations exist, we group small banks into a single category. Those institutions account for less than 5% of the total turnover in the CHF repo market. Overall, 50 bank-specific dummy variables were included in the regression.

To account for potential intra-class correlation, we use clustered standard errors. Some regressors are variables with a daily, monthly or quarterly frequency. Consequently, transactions e.g. settled on the same trading day exhibit the same values for some of the independent variables. Thus, the regression residuals of these observations might be serially correlated. As most of our independent variables have at least a daily observation frequency, we use standard errors clustered by trading day in the baseline regression. Another possibility would be to use standard errors clustered by cash taker. As we control for individual heterogeneity by including bank-specific dummy variables, clustering by trading day is preferred to clustering by cash taker.

[19] Standard probit and logit models show similar measures of goodness of fit (pseudo R^2 of about 0.19). To compare the two models, the fitted log-likelihoods are calculated (Cameron and Trivedi, 2005). Since the fitted log-likelihood of the logit model slightly outperforms the probit model, we focus on the logit model.

[20] Note that the dataset, containing a fixed number of participants and a large number of observations allows us to run an unconditional logit regression instead of a conditional logit regression (Cameron and Trivedi, 2005).

5.5 Regression results

The regression results are illustrated in Table 5 column (1).[21] We find a significant and negative effect of the availability of securities (i.e. pool of available securities) on the re-use probability. This implies that market participants tend to re-use in times when the availability of securities is low. Shocks in the collateral universe are thus (at least partially) absorbed by an increasing re-use activity. A shortage of available securities does consequently increase the re-use activity. The re-use of collateral therefore supports market activity in the CHF repo market, especially when available securities become scarce. This evidence supports Hypothesis 1.

Furthermore, the coefficient for securities borrowing (orth.) is positive and significant. The fewer securities borrowed from customers, the lower is the probability of collateral re-use. This clearly indicates that banks re-use collateral when they also borrow securities from client accounts (Hypothesis 2).

The coefficients for the duration of the transaction and the share of long-term transactions are statistically significant and confirm Hypothesis 3. The longer the duration of a transaction, the lower the probability for collateral re-use. Furthermore, the regression results show that collateral re-use does occur more often when the share of long-term repos in the market is high. Consequently, our findings support the hypothesis that the re-use of collateral is used to lend cash long-term and to borrow cash short-term. Re-use might thus enhance trading activity and reduce traders funding liquidity needs as proposed by Monnet (2011).

The coefficient for the relationship ratio indicates a negative impact of a weak diversification of the collateral provider on the re-use probability. Hence, if the re-using counterparty only borrows cash (lends collateral) from a few cash providers (i.e. the relationship ratio is high), it is more careful about re-using collateral. This supports Hypothesis 5 that re-using intermediaries might be worried about not receiving back their collateral, which they have to return to the initial collateral provider. However, the money market stress variable does not exhibit statistically significant coefficients. This might be due to the fact that the re-use of collateral is only observable for the re-using counterparty and not for the initial collateral provider. We therefore cannot confirm that money market stress has a negative impact on the re-use of collateral. Thus, we find no evidence supporting Hypothesis 4.

The coefficients of the control variables are partly significant and show the expected signs. The overall market activity (i.e. the outstanding volume) positively affects the re-use probability. The coefficients for the credit ratings show that especially the re-use probability for securities with no credit rating is reduced compared to the reference category (AAA-rating).

[21] The coefficients of a logit regression represent the log of the odds ratios. Interpretations in the following focus on the sign and the significance of the coefficients, which determine the direction of the corresponding marginal effect. The majority of the coefficients are significant at least at the 5% significance level including most of the coefficients for the bank-specific effects.

5.6 Predictions

The logit model is a non-linear model and therefore the coefficients cannot be interpreted as semi-elasticities (Winkelmann and Boes, 2006). We therefore calculate predicted re-use probabilities (conditional probabilities) for different levels of one independent variable, with all other variables held constant (see Figure 5).

The increase in the re-use probability tends to be non-linear especially for the duration of a transaction. The re-use probability decreases sharply with an increasing duration of the transaction. Whereas the re-use probability is around 40% in overnight transactions, it decreases to almost zero in transactions with a duration of more than 200 days. Moreover, also the securities borrowed (orth.) and available securities variables have a strong and non-linear impact on the re-use probability. For example, the predictions show that the re-use probability decreases from 41% to 31% when the pool of available securities increases from 50 to 100 bn. Furthermore, the outstanding volume exhibits a strong positive effect on the re-use probability.

Figure 4 shows the predicted re-use probabilities conditional on different credit rating categories. The figure reveals that the re-use activity also depends on the credit rating of the collateral. Especially, securities without credit rating (e.g. short-term government debt) are re-used less frequently.

5.7 Robustness

In order to check the robustness of our findings we run several additional regressions. First, we cluster standard errors by month (see Table 5 column (2)). All coefficients remain significant at least on a 5% level except the constant.[22] Second, we check the robustness with respect to the scarcity of collateral variables (i.e. securities borrowing and available securities). Table 5 column (3) and (4) report the regression results when dropping one of the two variables. In both cases, the remaining collateral availability variable persists to be significant with its corresponding sign, whereas other variables change only marginally. Finally, we also run a regression without bank-specific dummy variables (see Table 5 column (5)). Even though we neglect individual heterogeneity in this case, the model performs relatively well and most of the coefficients keep their sign and significance. The only exception is the money market stress variable which becomes negative and significant at the 5% level.

6 Concluding remarks

This paper sheds light on the re-use of collateral in an interbank repo market. By developing and applying an algorithm on transaction data from the CHF repo market, we are not only able to document the re-use activity, but also identify the drivers of collateral re-use before, during

[22] Clustering by quarter reveals similar results, see online appendix.

and after the financial crisis.

Our estimations show that on average the re-use rate was at about 0.1 prior to the financial crisis. With the reduction of available collateral just before the outbreak of the crisis, the re-use rate reached its maximum of almost 0.2, but declined significantly in the third quarter of 2008 and has not recovered yet. The results complete recent findings by Singh (2011) as well as Aitken and Singh (2009) in at least two important areas. First, we confirm by using actual transaction data that the re-use activity substantially declined after the financial crisis. Second, we show that the re-use within the interbank repo market can significantly differ from the level of rehypothecation.

The regression analysis provides evidence that the re-use activity depends on the availability of collateral. Market participants tend to re-use when collateral scarcity increases and in times when they also borrow securities from their client's. Further, we find evidence for a significant impact of the maturity of the transaction on the re-use probability. The longer the duration of a transaction, the lower is the probability that in this transaction a collateral re-use occurs.

With the methodology and the data at hand, future research on the re-use of collateral can be done. In particular, it might be worth investigating in the cross-currency and the cross-instrument re-use of collateral as well as the re-use activity of individual banks.

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A Appendix I

A.1 Selection of collateral in SECOM

The selection of securities for a repo transaction in SECOM can be done manually or automatically by the so-called 'GC select' algorithm. The majority of market participants use the automatic selection process. The GC select chooses securities from a predefined pool of available securities (SIX Securities Services, 2013). The pool of available securities (the so called 'release list') has to be maintained by the market participant. Besides other information included on the ISINs, the release list contains the corresponding quantity available, the date of the next coupon payment ('valid till date') and the date until the security is available for repos ('release till date', which is typically equal to the valid till date). Securities received in a repo are classified as 'purchased securities'. With the default setting, these securities are not shifted to the release list but to the so called 'non-release list'. Furthermore, the release till date of purchased securities is not equal to the valid till date as in the default setting, but equals the repurchase date of the initial transaction. However, market participants can change the default setting. Currently, two-thirds of all account owners adjust the default option such that purchased securities are automatically transferred to the release list.[23] This means that they intend to re-use collateral. Other account owners - using the default setting - still have the option of transferring specific ISINs from the non-release list to the release list.

For a repo transaction, the GC select picks securities by using a predefined methodology. First, it selects securities from the collateral category defined, then it rejects securities that are not eligible (e.g. own banking group securities) and finally it removes all securities that have a valid till date prior to the repurchase date of the repo transaction (SIX Securities Services, 2013). From this remaining list, the GC select first chooses the securities with the shortest possible release till date (SIX Securities Services, 2013), thus preferring the securities that stem from another transaction.

A.2 Re-use activity when relaxing the repurchase condition

The algorithm identifies a transaction as a re-use transaction only if the repurchase date of the re-use transaction is not later than the repurchase date of the initial transaction. However, a re-use might also occur without satisfying this condition, since the collateral taker of the initial transactions only has to return the same ISIN at the repurchase date - but not the same security. In this case, the collateral taker needs to obtain the same collateral somewhere else (e.g. secondary market) in order to return the security to the initial owner.

Figure 4 in the online appendix shows the estimated re-use without the repurchase condition. It becomes clear that the re-use identified is about twice as large but has a very similar pattern.

[23] Securities received from margin calls are transferred to the release list but flagged and are thus not available for the GC select.

The re-use activity without repurchase condition can be seen as an upper limit of the possible re-use activity in the CHF repo market.

A.3 Fungibility of ISINs and implications for the re-use

The algorithm might overestimate the re-use of collateral, as we are only able to compare the ISINs but cannot guarantee that exactly the same security has been re-used. Securities of the same issuance cannot be distinguished from each other - i.e. they are perfectly fungible. In other words, a security - with the same ISIN as the purchased security in the repo transaction - could have already been on the release list and then used in the re-use transaction. The algorithm would identify this as a re-use. However, as the GC select first chooses collateral with the youngest release till date, and purchased securities automatically have an earlier release till date than the same ISIN in the account, we do not expect the overestimation to be significant.

A.4 Figures

Figure 1: Outstanding volume based on re-used collaterals

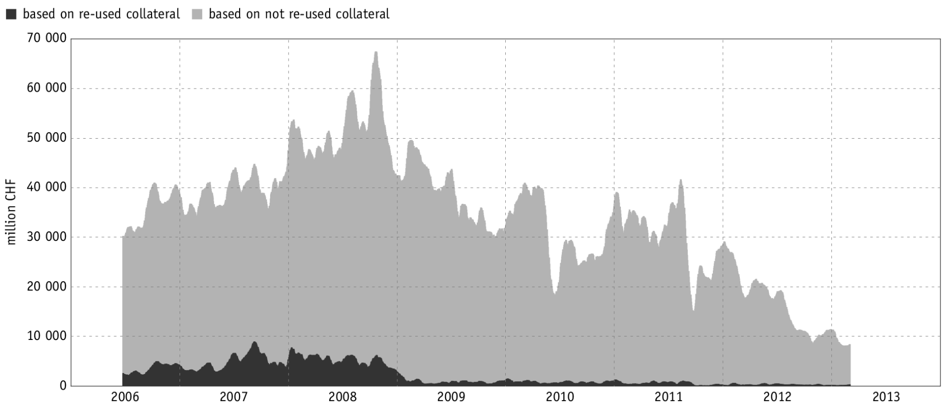


Figure 1 shows the outstanding volume based on re-used collateral. The dark grey area is based on re-used collateral, whereas the light grey area stacked on top corresponds to the outstanding volume without re-use (15 day moving average).

Figure 2: Re-use rate and outstanding volume

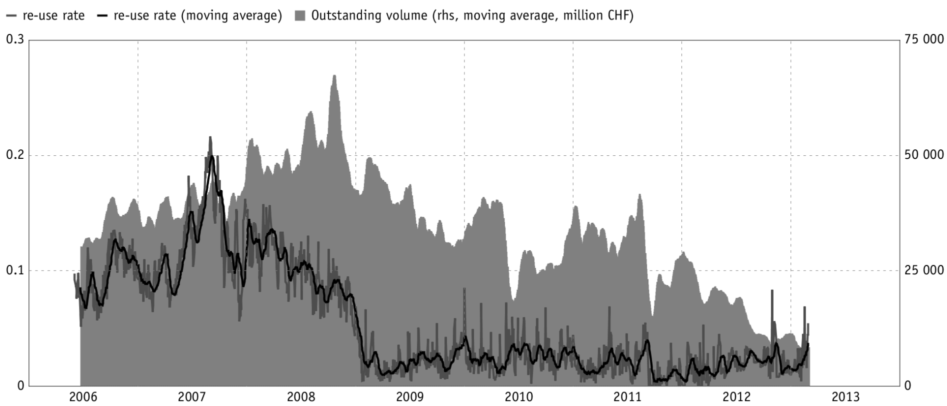


Figure 2 shows the collateral multiplier over time. The grey area is the total outstanding volume in the CHF interbank repo market (15 day moving average). The light grey line is the daily re-use rate, whereas the black line is the re-use rate with a 15 day moving average.

Figure 3: Collateral multiplier and available securities

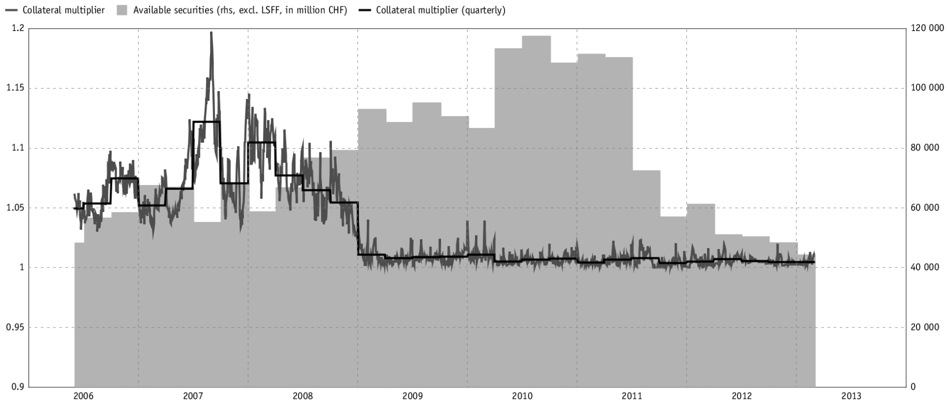


Figure 3 shows the collateral multiplier over time. Available securities are SNB eligible securities minus the securities held in the custody cover account "SNB" for the liquidity-shortage financing facility (grey bars). The light grey line is the daily collateral multiplier, whereas the black line is the collateral multiplier on a quarterly basis.

Figure 4: Credit ratings

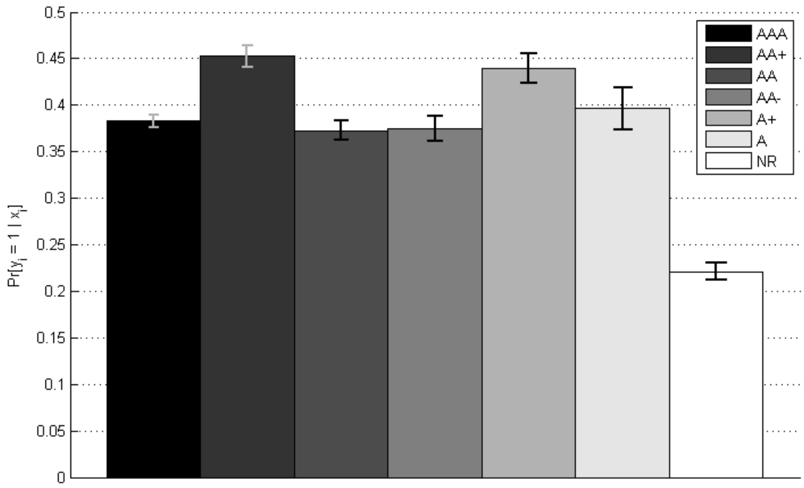


Figure 4 shows the predicted re-use probabilities for different rating categories. The vertical axis is the estimated probability of a re-use conditional on the rating category, with all other variables held constant. The predicted re-use probabilities are based on the regression coefficients. The vertical lines illustrate the corresponding 95% confidence intervals. Note that securities with a credit rating lower than AA- must be denominated in CHF.

Figure 5: Predictions

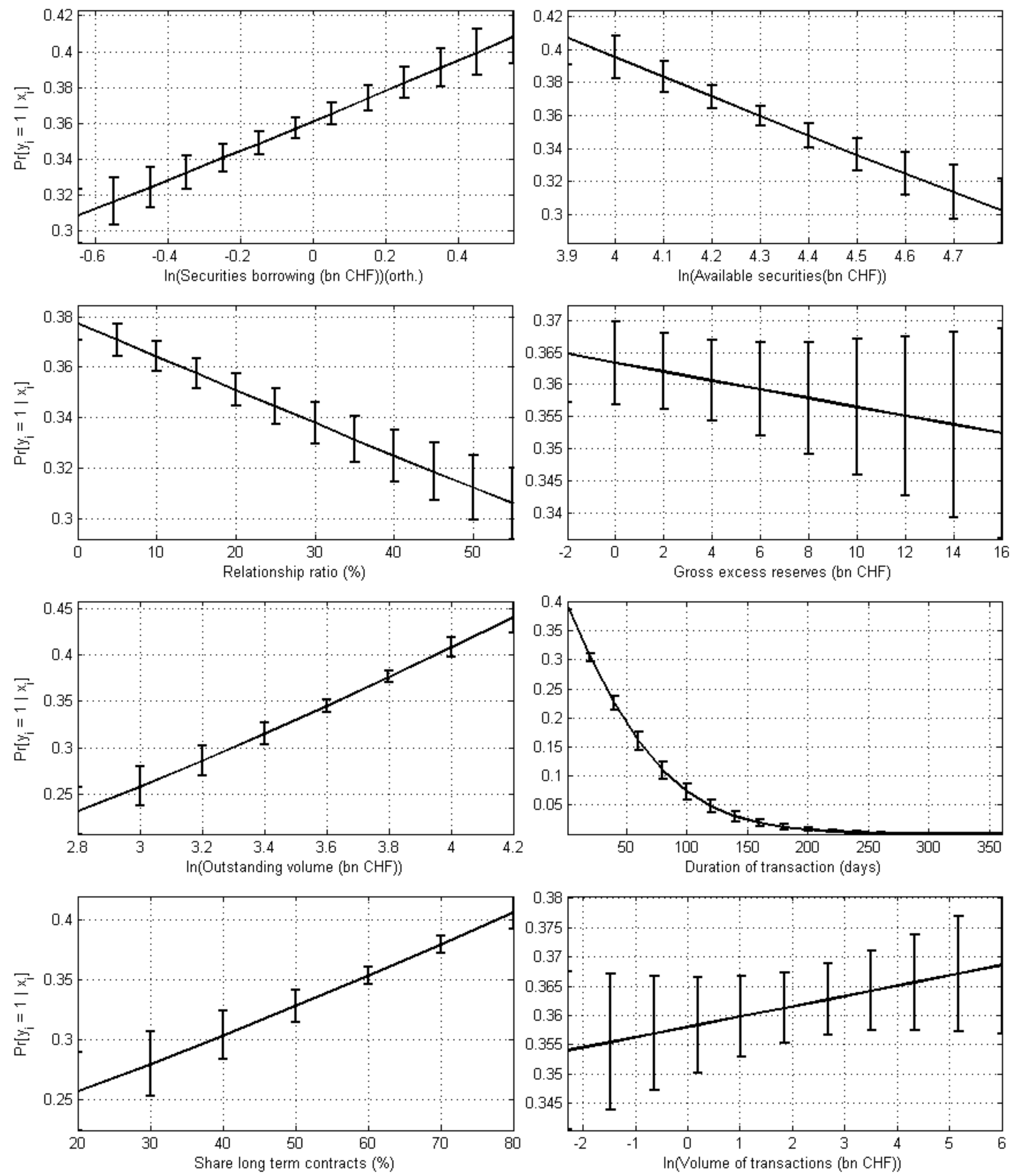


Figure 5 shows the predicted re-use probabilities for different levels of a variable. The vertical axis is the estimated probability of a re-use conditional on different levels of the explanatory variable, with all other variables held constant. The predicted re-use probabilities are based on the significant regression coefficients. The vertical lines illustrate the corresponding 95% confidence intervals. The predicted re-use probabilities need to be considered as hypothetical values, since certain values in certain periods simply did not exist, e.g. the gross excess reserves before the crisis never exhibited values as large as after the crisis.

A.5 Tables

Table 1: Securities holdings of banks domiciled in Switzerland

	2006	2007	2008	2009	2010	2011	2012
Total securities holdings	555,214	551,003	298,703	309,895	321,493	266,825	261,764
In % of total balance sheet	17.4%	15.9%	9.7%	11.6%	11.8%	9.6%	9.4%
Securities borrowing	237,257	271,875	97,549	78,728	66,259	57,208	51,439
SNB eligible securities	64,877	96,995	115,237	127,683	145,394	91,932	84,088
In % of total securities	11.7%	17.6%	38.6%	41.2%	45.2%	34.5%	32.1%
Held in LSFF*	12,100	33,700	34,500	35,900	37,500	32,900	33,700
Available securities**	52,777	63,295	80,737	91,783	107,894	59,032	50,388

In CHF million; * Liquidity-shortage financing facility
**Available securities for repos = SNB eligible − held in LSFF
Source: SNB statistical publications, "Banks in Switzerland"; SNB accountability reports.

Table 2: Number of initial and re-use transactions

# of re-use	1	2	3	4	5	≥ 6	Total
Initial transaction	8,352	3,893	2,352	1,538	1,079	4,156	21,370
Re-use transaction	8,352	7,786	7,056	6,152	5,395	50,430	85,171
In % all re-use transactions	9.8%	9.1%	8.3%	7.2%	6.3%	59.2%	100.0%

Table 3: Distribution of re-use by maturity of initial (rows) and re-use (columns) transaction

	day-to-day*	1W	1W-1M	1M-3M	3M-6M	6M-12M	Total
day-to-day*	100.0%	-	-	-	-	-	2,957
1W	95.3%	4.7%	-	-	-	-	5,764
1W-1M	88.1%	7.2%	4.7%	-	-	-	32,140
1M-3M	81.7%	8.7%	8.5%	1.2%	-	-	32,347
3M-6M	71.3%	9.0%	13.1%	6.3%	0.4%	-	12,534
6M-12M	86.3%	5.8%	4.3%	2.4%	1.2%	0.0%	1,761
Total	84.2%	7.6%	6.8%	1.4%	0.1%	0.0%	87,503

* day-to-day maturities are: overnight, tom-next, spot-next

Table 4: Descriptive statistics

Variable name	Unit	Freq.	Agg.	Abb.	Mean	Std. dev.	Min.	Max.
Collateral re-use	dummy	t	i	Y	0.36	0.48	0.00	1.00
ln(Securities borrowing)	ln(bn)	m	o	SB	5.19	0.51	4.11	5.65
ln(Available securities)	ln(bn)	q	o	AP	4.29	0.24	3.88	4.77
Stress in money market	pp	d	o	MS	0.15	0.40	-0.09	3.28
Relationship ratio	%	d	i	RE	11.25	16.56	0.00	100.00
Share long-term transactions	%	d	o	LT	63.01	10.19	20.10	82.57
Duration of transaction	days	t	i	DU	8.78	24.22	1.00	370.00
Rating AAA	dummy	t	i	RA	0.61	0.49	0.00	1.00
Rating AA+	dummy	t	i	RA	0.08	0.28	0.00	1.00
Rating AA	dummy	t	i	RA	0.06	0.24	0.00	1.00
Rating AA-	dummy	t	i	RA	0.04	0.19	0.00	1.00
Rating A+	dummy	t	i	RA	0.02	0.14	0.00	1.00
Rating A	dummy	t	i	RA	0.01	0.10	0.00	1.00
No rating	dummy	t	i	RA	0.18	0.38	0.00	1.00
Gross excess reserves	bn	d	i	GE	1.91	5.13	-2.68	303.94
Market maker	dummy	d	i	MM	0.20	0.40	0.00	1.00
ln(Outstanding volume)	ln(bn)	d	o	OV	3.70	0.23	2.73	4.28
ln(Volume of transaction)	ln(mn)	t	i	VA	2.225	1.64	-15.53	6.02

Number of observations 234,000

Table 4 shows the descriptive statistic of dataset used. Freq. = Frequency of variables: t = for each transaction, d = daily, m = monthly, q = quarterly. Agg. = Aggregation of variables: i = individual, o = over all banks. Abb. = Abbreviation of variables.

Table 5: Regression results

	(1) Baseline	(2) S.E. by month	(3) Excl. SLB	(4) Excl. Pool	(5) No F.E.
Scarcity of collateral					
ln(Available securities (bn CHF))	-0.652***	-0.652***	-0.457***		-0.496***
	(-5.91)	(-2.88)	(-4.20)		(-5.04)
ln(Securities borrowing) (orth.)	0.462***	0.462***		0.353***	0.551***
	(7.03)	(3.93)		(5.49)	(8.88)
Maturity of transactions					
Share long-term transactions (in %)	0.0143***	0.0143***	0.0161***	0.0217***	0.00841***
	(6.12)	(2.92)	(6.81)	(11.06)	(3.91)
Duration of transaction (days)	-0.0245***	-0.0245***	-0.0240***	-0.0243***	-0.0302***
	(-20.76)	(-11.99)	(-20.77)	(-20.69)	(-21.98)
Control variables					
Stress in money market (pp)	-0.0539	-0.0539	-0.104	-0.106	-0.161**
	(-0.71)	(-0.91)	(-1.36)	(-1.42)	(-2.41)
Relationship ratio (in %)	-0.00735***	-0.00735***	-0.00764***	-0.00827***	-0.00165**
	(-8.21)	(-4.44)	(-8.46)	(-9.38)	(-2.23)
Rating AA+ (dummy)	0.363***	0.363***	0.360***	0.343***	0.209***
	(13.73)	(6.47)	(13.57)	(12.93)	(8.38)
Rating AA (dummy)	-0.0538**	-0.0538	-0.0570**	-0.0615**	-0.104***
	(-2.05)	(-1.05)	(-2.17)	(-2.34)	(-4.27)
Rating AA- (dummy)	-0.0439	-0.0439	-0.0326	-0.0330	-0.0926***
	(-1.23)	(-0.53)	(-0.91)	(-0.92)	(-2.90)
Rating A+ (dummy)	0.295***	0.295***	0.312***	0.311***	0.258***
	(6.85)	(3.38)	(7.17)	(7.23)	(6.75)
Rating A (dummy)	0.0708	0.0708	0.0746	0.0694	0.140***
	(1.15)	(0.48)	(1.19)	(1.11)	(2.68)
No rating (dummy)	-0.952***	-0.952***	-0.943***	-0.938***	-1.030***
	(-30.65)	(-10.71)	(-30.15)	(-29.74)	(-33.87)
Gross excess reserves (bn CHF)	-0.00382	-0.00382	-0.00822**	-0.00872**	-0.0125***
	(-1.21)	(-0.72)	(-2.27)	(-2.30)	(-3.02)
Market maker (dummy)	-0.0107	-0.0107	0.0119	0.00827	-0.0373
	(-0.25)	(-0.17)	(0.28)	(0.20)	(-0.91)
ln(Outstanding volume (bn CHF))	0.859***	0.859***	1.073***	0.994***	0.375***
	(9.39)	(4.51)	(12.01)	(11.59)	(3.99)
ln(Volume of transaction (mn CHF))	0.00974	0.00974	0.00492	0.00517	0.0170**
	(1.28)	(0.44)	(0.64)	(0.68)	(2.56)
Constant	-2.076***	-2.076	-3.841***	-5.856***	-0.00661
	(-2.76)	(-1.28)	(-5.27)	(-15.92)	(-0.01)
Number of observations	234000	234000	234000	234000	236242
Pseudo R-squared	0.189	0.189	0.187	0.187	0.0616
Log-likelihood	-124242.6	-124242.6	-124497.1	-124445.2	-144664.0
Log-likelihood (0)	-153159.2	-153159.2	-153159.2	-153159.2	-154160.5

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5 shows the regression results of our baseline regression (column (1)) and the applied robustness tests (column (2) - (5)). The baseline regression reveals the results with standard errors clustered by date and bank-specific dummy variables. Column (2) shows the regression results with standard errors clustered by month, column (3) the results without the securities borrowing (orth.) variable and column (4) the regression results without the available securities variable. Column (5) shows the regression results when dropping bank-specific dummy variables. The coefficients of a logit regression represent the log of the odds ratios. The predicted re-use probabilities for different variables from the baseline regression (column (1)) are given in Figure 5. The sample period lasts from June 2006 - August 2011. Further robustness checks regarding the selection of the starting date can be found in the online appendix. For variables in cash amounts we employ the natural log if they are $\gg 0$. Bank-specific dummy variables are not reported (column (1) - (4)). The securities borrowing (orth.) variable is orthogonalised as specified in Equation 3.

B Appendix II (online appendix)

B.1 Robustness check: underestimation

The dataset used includes repo transactions as well as the corresponding collateral information ranging from 1 March 2006 until 28 February 2013. As noted in Section 3, the algorithm underestimates the re-use of collateral in the first months of the observation period, as we cannot observe initial collateral transactions before March 2006. With maturities of repo transactions of up to one year, there is accordingly an underestimation issue during the first twelve months, i.e. until the end of February 2007. Therefore, between March 2006 and end of February 2007 the re-use rate is underestimated due to the fact that potential initial transactions are missing.

$$\text{re-use} = \begin{cases} \text{01.03.2006 - 30.05.2006} & \text{Underestimation and exclusion} \\ \text{01.06.2006 - 28.02.2007} & \text{Potential underestimation} \\ \text{01.03.2007 - 28.02.2013} & \text{unbiased} \end{cases}$$

We further approached the underestimation problem by looking at potential initial transactions that we are missing. In fact, we do have access to the transaction data before March 2006 (but without the according collateral information) which allows us to evaluate the value of potential initial transactions. Put differently, the composition of the outstanding volume as of 1 March 2006 is known. Figure 6 reveals the outstanding volume of transactions conducted between 1 March 2005 and 28 February 2006 with a repurchase date after the start of our observation period. These transactions can potentially serve as initial transaction for a re-use in the observation period in the scope of their outstanding volume and thus give an indication of the magnitude of the underestimation of the re-use. The outstanding volume of these transactions lies at roughly CHF 35 bn. by beginning of March 2006 but declines rapidly afterwards. By 1 June 2006 less than CHF 5 bn. (or 13% of the initial outstanding volume) and by 1 September 2006 less than CHF 70 mn. (or less than 1% of the initial outstanding volume) are still outstanding. By 23 February 2007 all potential transactions that could serve as initial transaction are matured. Overall, Figure 1 reveals that the outstanding volume of missing potential initial transactions declines rapidly.

In order to account for the potential underestimation problem in the regression analysis, we computed robustness checks by adjusting the sample range. In Table 6 we first show our baseline regression results, i.e. using 1 June 2006 as starting date (first vertical line in Figure 6; column (1)) second, we use 1 September 2006 as the starting date of the regression (second vertical line in Figure 6; column (2)). Third, we use 23 February 2007 as the starting date of the regression (third vertical line in Figure 6 with no underestimation anymore; column (3)). The regression results reveal that our findings from the baseline regression are robust to changes of the starting date. The sign as well as the statistical significance of all relevant coefficients remain basically unchanged. Only the control variables "Gross Excess Reserves" (in both regressions) and the dummy variable for "Market Makers" gain statistical significance, the latter, however, only at a confidence level of 10%.

Figure 6: Maturity structure of the outstanding volume

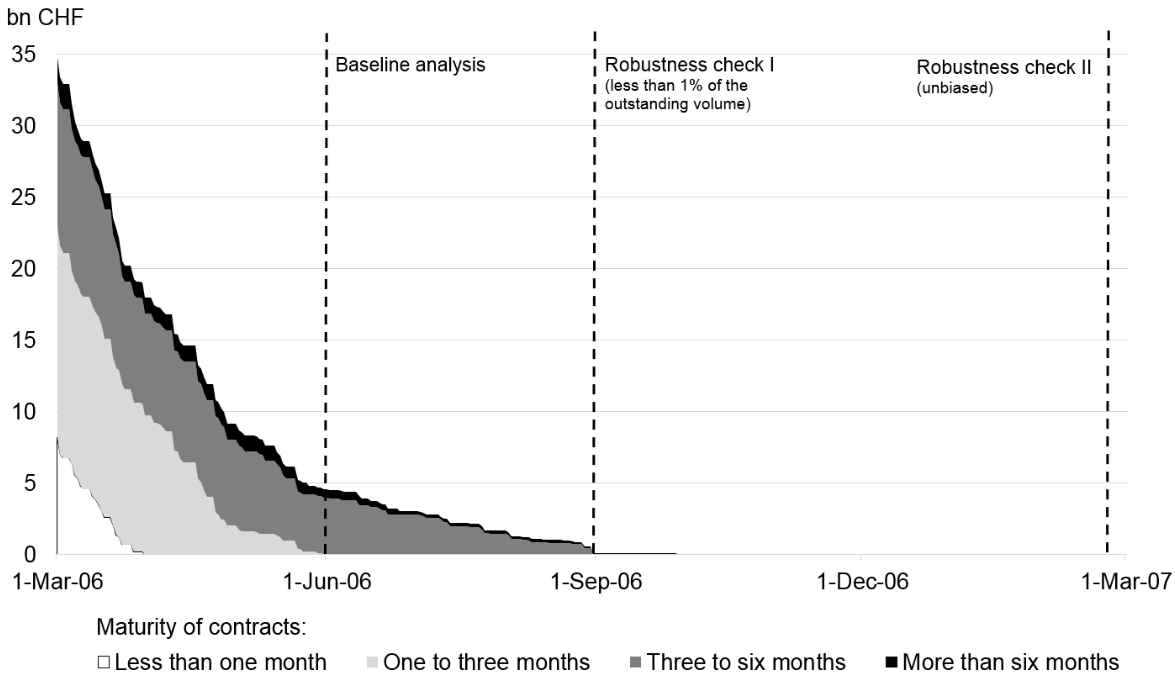


Figure 6 shows the maturity structure of the outstanding volume of transactions conducted between 1 March 2005 and 28 February 2006 with a repurchase date after the start of our observation period. These transactions can potentially serve as initial transaction for a re-use in the observation period in the scope of their outstanding volume and thus give an indication of the magnitude of the underestimation of the re-use at the beginning of the observation period. As of 1 March 2006, the outstanding volume of those transactions is roughly CHF 35 bn. with a maturity structure such that by 1 June 2006 about CHF 5 bn. (or 13%), by 1 September 2006 about CHF 70 mn. (or less than 1%) and by 23 February 2007 zero interbank transactions are outstanding.

Table 6: Regression results with different starting dates

	(1) Baseline	(2) 1 September 2006	(3) 24 February 2007
Scarcity of collateral			
ln(Available securities (bn CHF))	-0.652***	-0.782***	-0.820***
	(-5.91)	(-6.25)	(-6.15)
ln(Securities borrowing) (orth.)	0.462***	0.403***	0.309***
	(7.03)	(5.99)	(4.38)
Maturity of transactions			
Share long-term transactions (in %)	0.0143***	0.0120***	0.0122***
	(6.12)	(4.96)	(5.26)
Duration of transaction (days)	-0.0245***	-0.0254***	-0.0275***
	(-20.76)	(-20.45)	(-18.28)
Control variables			
Stress in money market (pp)	-0.0539	-0.0357	-0.0291
	(-0.71)	(-0.47)	(-0.38)
Relationship ratio (in %)	-0.00735***	-0.00748***	-0.00864***
	(-8.21)	(-8.14)	(-8.80)
Rating AA+ (dummy)	0.363***	0.388***	0.397***
	(13.73)	(14.53)	(14.34)
Rating AA (dummy)	-0.0538**	-0.0420	-0.0232
	(-2.05)	(-1.55)	(-0.81)
Rating AA- (dummy)	-0.0439	-0.0513	-0.154***
	(-1.23)	(-1.39)	(-3.78)
Rating A+ (dummy)	0.295***	0.309***	0.223***
	(6.85)	(6.88)	(4.57)
Rating A (dummy)	0.0708	0.0810	0.0447
	(1.15)	(1.30)	(0.69)
No rating (dummy)	-0.952***	-0.953***	-1.014***
	(-30.65)	(-29.53)	(-25.84)
Gross excess reserves (bn CHF)	-0.00382	-0.00579*	-0.0122***
	(-1.21)	(-1.72)	(-2.80)
Market maker (dummy)	-0.0107	-0.0197	-0.0882*
	(-0.25)	(-0.44)	(-1.78)
ln(Outstanding volume (bn CHF))	0.859***	0.725***	0.545***
	(9.39)	(7.12)	(4.91)
ln(Volume of transaction (mn CHF))	0.00974	0.0104	0.00843
	(1.28)	(1.30)	(0.93)
Constant	-2.076***	-0.856	-0.0517
	(-2.76)	(-0.96)	(-0.05)
Number of observations	234000	218715	188497
Pseudo R-squared	0.189	0.190	0.197
Log-likelihood	-124242.6	-116644.8	-99831.1
Log-likelihood (0)	-153159.2	-143967.0	-124316.2

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6 column (1) shows the regression results of our baseline regression, i.e. using 1 June 2006 as starting date. Column (2) shows the regression results when using 1 September 2006 (instead of 1 June 2006) as starting date. With this specification less than 1% of the outstanding volume of potential initial transaction that are missing as of 1 March 2006 is outstanding. Column (3) shows the regression results when using 24 February 2007 as starting date. With this specification the regression does not suffer any potential underestimation. For variables in cash amounts we employ the natural log if they are $\gg 0$. Bank-specific dummy variables are not reported. The securities borrowing (orth.) variable is orthogonalised as specified in Equation 3. For all regression specifications the sample period lasts until August 2011.

B.2 Robustness check: clustering

Table 7: Regression results with standard errors clustered by date, month and quarter

	(1) Baseline	(2) Month	(3) Quarter
Scarcity of collateral			
ln(Available securities (bn CHF))	-0.652***	-0.652***	-0.652**
	(-5.91)	(-2.88)	(-2.56)
ln(Securities borrowing) (orth.)	0.462***	0.462***	0.462***
	(7.03)	(3.93)	(2.97)
Maturity of transactions			
Share long-term transactions (in %)	0.0143***	0.0143***	0.0143***
	(6.12)	(2.92)	(2.67)
Duration of transaction (days)	-0.0245***	-0.0245***	-0.0245***
	(-20.76)	(-11.99)	(-10.39)
Control variables			
Stress in money market (pp)	-0.0539	-0.0539	-0.0539
	(-0.71)	(-0.91)	(-0.71)
Relationship ratio (in %)	-0.00735***	-0.00735***	-0.00735***
	(-8.21)	(-4.44)	(-3.49)
Rating AA+ (dummy)	0.363***	0.363***	0.363***
	(13.73)	(6.47)	(4.57)
Rating AA (dummy)	-0.0538**	-0.0538	-0.0538
	(-2.05)	(-1.05)	(-0.97)
Rating AA- (dummy)	-0.0439	-0.0439	-0.0439
	(-1.23)	(-0.53)	(-0.38)
Rating A+ (dummy)	0.295***	0.295***	0.295**
	(6.85)	(3.38)	(2.38)
Rating A (dummy)	0.0708	0.0708	0.0708
	(1.15)	(0.48)	(0.34)
No rating (dummy)	-0.952***	-0.952***	-0.952***
	(-30.65)	(-10.71)	(-7.13)
Gross excess reserves (bn CHF)	-0.00382	-0.00382	-0.00382
	(-1.21)	(-0.72)	(-0.52)
Market maker (dummy)	-0.0107	-0.0107	-0.0107
	(-0.25)	(-0.17)	(-0.16)
ln(Outstanding volume (bn CHF))	0.859***	0.859***	0.859***
	(9.39)	(4.51)	(3.41)
ln(Volume of transaction (mn CHF))	0.00974	0.00974	0.00974
	(1.28)	(0.44)	(0.27)
Constant	-2.076***	-2.076	-2.076
	(-2.76)	(-1.28)	(-1.09)
Number of observations	234000	234000	234000
Pseudo R-squared	0.189	0.189	0.189
Log-likelihood	-124242.6	-124242.6	-124242.6
Log-likelihood (0)	-153159.2	-153159.2	-153159.2

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7 column (1) shows the baseline regression results, i.e. with standard errors clustered by day. Column (2) shows the regression results with standard errors clustered by month and column (3) the regression results with standard errors clustered by quarter. For variables in cash amounts we employ the natural log if they are $\gg 0$. Bank-specific dummy variables are not reported. The securities borrowing (orth.) variable is orthogonalised as specified in Equation 3. The sample period lasts from 1 June 2006 until 2 August 2011.

B.3 Figures

Figure 7: Individual re-use rates

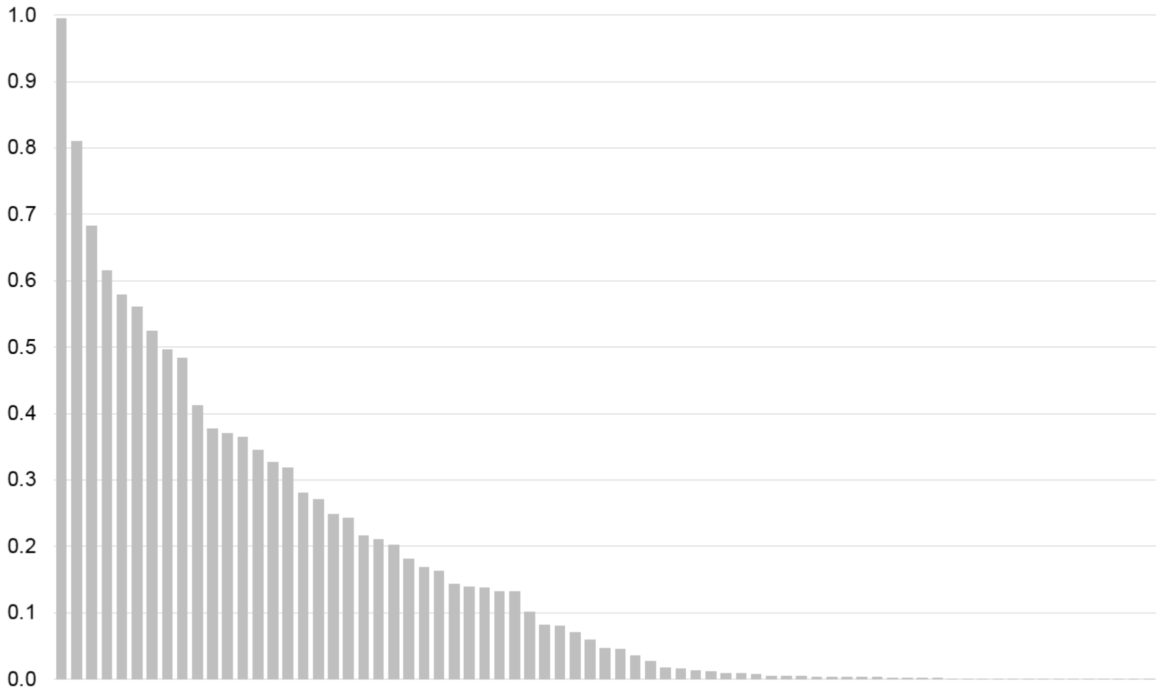


Figure 7 shows the individual re-use rates of the 73 market participants that re-used securities at least once and their average outstanding volume as cash taker and cash provider between 1 June 2006 and 28 February 2013. The re-use rate varies significantly among different market participants. Overall, about 30 banks have an average re-use rate of above 0.1.

Figure 8: Use and re-use of securities

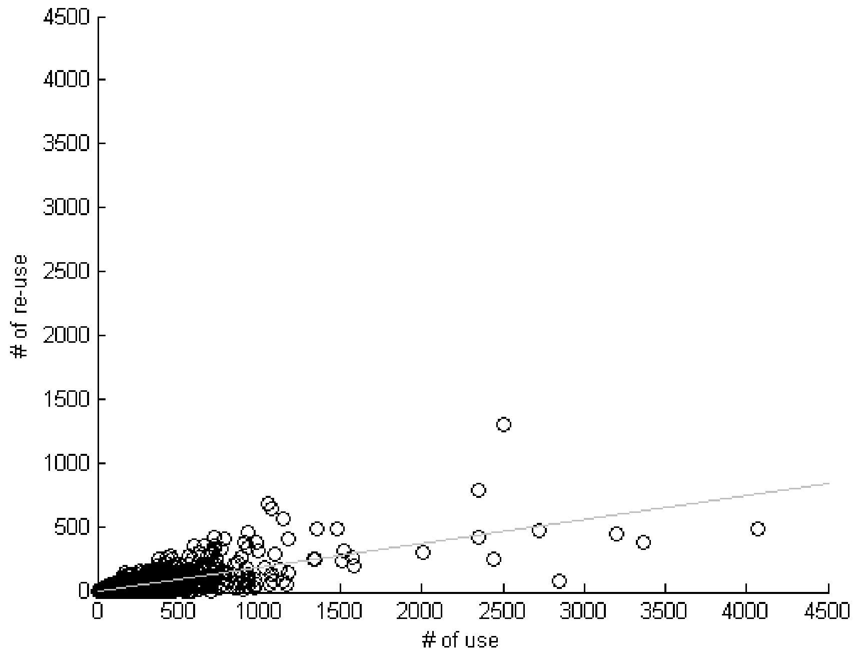
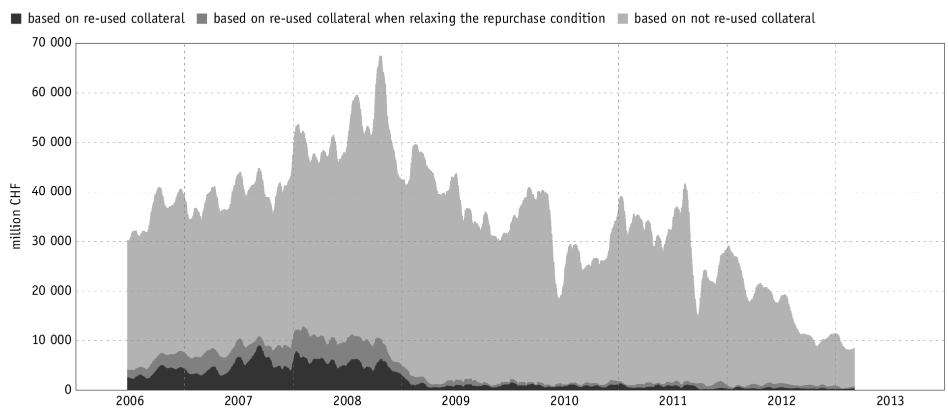


Figure 8 shows on the horizontal axis the total number of transactions, where a specific security was used and on the vertical axis the total number of transactions, where this specific security was re-used. Therefore, each point represents the number of uses and re-uses of a specific security. The grey line represents the least-squares fit with intercept −1.00 (Std. err. 0.564) and slope 0.19 (Std. err. 0.002). Overall, the plot indicates that there is no disproportionate re-use of specific securities. In total, there were 4,419 different securities used. The median security was used 44 times and re-used three times.

Figure 9: Outstanding volume when relaxing the repurchase condition



The black area is based on re-used collateral with repurchase condition. The dark grey area is based on re-used collateral when relaxing the repurchase condition, whereas the light grey area that is stacked on top corresponds to the outstanding volume without re-use condition (15 day moving average).

Figure 10: Balance sheet effects of repo transactions

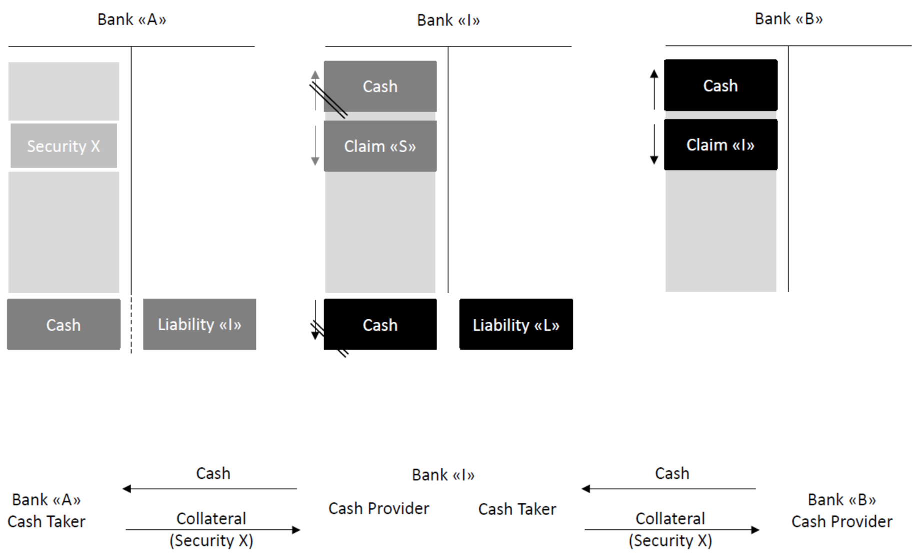


Figure 10 is based on the prevailing accounting treatment of repo transactions (Wechsler, 1999). A repo transaction increases the cash taker's balance sheet, whereas it leads to a reallocation on the cash provider's asset side of the balance sheet.

B.4 Tables

Table 8: Pair-wise correlation between independent variables

	Available securities	Securities borrowing	Relationship ratio	Stress in money market	Gross excess reserves	Market maker	Outstanding volume	Duration of transaction	Volume of transaction	Long-term transaction
Available securities	1.00									
Securities borrowing	-0.85	1.00								
Relationship ratio	0.29	-0.29	1.00							
Stress in money market	0.00	0.03	-0.08	1.00						
Gross excess reserves	0.03	-0.05	-0.06	0.08	1.00					
Market maker	-0.10	0.14	-0.02	0.09	0.02	1.00				
Outstanding volume	-0.29	0.40	-0.23	0.49	0.08	0.18	1.00			
Duration of transaction	-0.10	0.13	-0.02	-0.03	0.01	-0.12	0.03	1.00		
Volume of transaction	0.17	-0.18	0.23	-0.01	-0.04	0.05	-0.04	-0.06	1.00	
Long-term transaction	-0.64	0.58	-0.21	0.03	-0.01	0.06	0.18	0.09	-0.14	1.00

Appendix II

The Liquidity Coverage Ratio and Security Prices*

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Abstract

What is the added value of a security which qualifies as a “high-quality liquid asset” (HQLA) under the Basel III “Liquidity Coverage Ratio” (LCR)? In this paper, we quantify the added value in terms of yield changes and, as suggested by Stein (2013), call it HQLA premium. To do so, we exploit the introduction of the LCR in Switzerland as a unique quasi-natural experiment and we find evidence for the existence of an HQLA premium in the order of 4 basis points. Guided by theoretical considerations, we claim that the HQLA premium is state dependent and argue that our estimate is a lower bound measure. Furthermore, we discuss the implications of an economically significant HQLA premium. Thereby, we contribute to a better understanding of the LCR and its implications for financial markets.

JEL Classification: E50, G10, G18, G21, G28
Keywords: Basel III, Liquidity Coverage Ratio, high-quality liquid assets, HQLA premium

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1 Introduction

The recent financial crisis has highlighted how important it is for banks to hold an adequate liquidity buffer in order to withstand severe short-term liquidity shocks. In an effort to strengthen banks' resilience against such shocks, the Basel Committee on Banking Supervision proposed the introduction of an internationally harmonized liquidity standard, the "Liquidity Coverage Ratio" (LCR), as part of the Basel III reforms (Basel Committee on Banking Supervision, 2013). The LCR requires banks to hold an adequate stock of "high-quality liquid assets" (HQLA), consisting of so-called "Level 1" and "Level 2" assets, relative to their expected net cash outflows (NCOF).

In this paper we examine the question as to whether the classification of a security as either Level 1, Level 2, or non-HQLA affects its market price. The change in the market price triggered by the LCR is measured by the yield spread between Level 1 and non-HQLA as well as Level 1 and Level 2 securities respectively and we refer to the change in the spread as the "HQLA premium" as suggested by Stein (2013). Guided by theoretical considerations, we identify the determinants of the HQLA premium. Subsequently, we quantify the HQLA premium for securities denominated in Swiss francs (CHF) empirically. Overall, our research question is inspired by literature suggesting that investors value the liquidity characteristics of a security.[1]

The key findings from our theoretical analysis are as follows: First, the size of the HQLA premium depends on the additional demand for HQLA caused by the LCR requirement, the elasticity of the HQLA supply, and the degree to which banks can reduce their NCOF. For example, if the LCR requires banks to increase their holdings of HQLA securities relative to their preferred portfolio allocation without LCR and if HQLA securities are scarce, the additional demand has a price impact and hence the HQLA premium is positive. Second, the price impact of the LCR requirement depends on the monetary policy environment. In an environment with substantial excess central bank reserves (reserves) and with the interest rate paid on reserves equal to the yield on HQLA securities, the HQLA premium is likely to be negligible.

In our empirical analysis, we consider a comprehensive dataset of homogenous fixed-income securities denominated in euro (EUR) and CHF which used to qualify uniformly as "liquid assets" under the liquidity regulation in Switzerland that was in place before Basel III. We take advantage of the change in the Swiss liquidity regulation which affects securities denominated in CHF and we use securities denominated in EUR as a control group. By using a difference-in-difference approach, we exploit the regulatory change as a unique quasi-natural experiment to estimate the HQLA premium.

The introduction of the LCR in Switzerland affects the regulatory treatment of formerly liquid assets in one of the following three ways: the security will be treated the same as it was under the former liquidity regulation if it qualifies as a Level 1 asset; it will be subject to a

[1]See Amihud and Mendelson (1986), Ashcraft, Garleanu and Pedersen (2010), Krishnamurthy and Vissing-Jorgensen (2012), Nagel (2016), Chapman, Chiu and Molico (2011), and Nyborg (2015).

regulatory downgrade if it qualifies as a Level 2 asset or it will no longer have any regulatory value under the LCR if it qualifies as a non-HQLA asset. Consequently, the regulatory change exogenously affects the relative attractiveness of securities and hence their prices.

Empirically, we find that there has been a price differentiation between Level 1, Level 2 and non-HQLA securities before the regulatory change which can be attributed to both the credit and liquidity risk of the corresponding securities. In case of Level 1 and non-HQLA securities and for the sample period under consideration, this price differentiation was in the order of 40 basis points (bps). The announcement of the detailed LCR principles reinforced this price differentiation. Our baseline analysis suggests that the HQLA premium is currently in the order of 4 bps and the applied robustness checks yield no discrepancies from the baseline results. We argue that the rather small HQLA premium for CHF-denominated securities is primarily due to substantial excess reserves and market interest rates close to the interest rate on reserves, which is a result of the Swiss National Bank's (SNB) monetary policy.

Our findings are relevant in the following ways: First, it is important to recognize that the LCR has introduced an HQLA premium, and that if this premium is non-zero, it affects the equilibrium relationship between asset prices and central bank policy rates (see Bech and Keister (2014) as well as BIS Committee on the Global Financial System (2015)). Hence, to establish the desired monetary conditions, central banks may need to target a different level for their policy rates. Moreover, if there is a scarcity of HQLA, banks' demand for reserves will increase to ensure compliance with the LCR. This will force central banks to operate with a larger balance sheet than they would have done in a scenario without LCR (see Debelle (2011)). Furthermore, the existence of an HQLA premium may also affect the choice of monetary policy instruments deployed to exit unconventional monetary policy (see Berentsen, Kraenzlin and Müller (2015)).

Second, our analysis suggests that issuing non-HQLA or Level 2 securities can become more expensive relative to Level 1 securities. Specifically, the LCR creates more favorable issuance conditions for HQLA securities (typically public debt) compared to non-HQLA securities (typically private debt). Consequently, the LCR incentivizes the production of such assets and may ultimately cause a re-allocation of resources in the real economy (see Nyborg (2015)).

Third, our results have implications for collateral frameworks of central banks. On the one hand, if central banks accept both HQLA and non-HQLA securities as collateral in their monetary policy operations, banks may increasingly come to rely on central bank funding against non-HQLA securities if haircuts are not adjusted accordingly (HQLA upgrade trade), thereby extending systemic arbitrage, as defined and discussed in Nyborg (2016) and Nyborg (2015) and further documented by Fecht, Nyborg, Rocholl and Woschitz (2016). On the other hand, if central banks align their collateral policy to the definition of HQLA, they may reinforce the price differentiation even further.

The remainder of this paper is structured as follows: Section 2 gives an overview on the literature. Section 3 describes the LCR. Section 4 defines the HQLA premium and presents a simple model for studying its determinants. Section 5 describes the empirical analysis. Section 6 discusses the results. Section 7 reflects on policy implications and finally, Section 8 concludes.

2 Literature

This paper is related to three strains of literature. First, our paper is related to the literature which studies the impact of the LCR in a broad sense. Based on a theoretical model, Bech and Keister (2014) study the impact of the LCR in jurisdictions with a scarcity of HQLA. They show that the LCR can affect security prices and describe how the introduction of a committed liquidity facility, i.e. a standing facility offered by the central bank where non-HQLA securities can be upgraded to HQLA securities, limits the price impact of the LCR on security prices and thus sets an upper bound for the HQLA premium.[2] Related to this, Stein (2013) suggests that the HQLA premium is state-dependent. In other words, if HQLA securities are in ample supply, the HQLA premium is expected to be low, whereas if HQLA securities are scarce, the HQLA premium is expected to be large. Banerjee and Mio (2014) analyze the impact of the liquidity regulation on banks' balance sheets and find that banks subject to the LCR have adjusted the composition of their assets towards HQLA. Other related papers are Bonner (2012) and Bonner and Eijffinger (2012) which analyze the impact of the "Dutch liquidity ratio" on banks' retail and interbank lending conditions.

Second, our paper is related to literature on the interaction between the safety and liquidity characteristics of an asset and its price. Krishnamurthy and Vissing-Jorgensen (2012) show that the yield spread between US corporate bonds and US Treasuries is high in periods with a relative scarcity of US Treasuries and vice versa. The authors thus provide evidence that investors value the liquidity and credit quality of US Treasuries as a safe asset and demonstrate that this premium is a function of the supply of these assets. Along the same line of argumentation, Carlson, Duygan-Bump, Natalucci, Nelson, Ochoa, Stein and Van den Heuvel (2014) show that this premium might even increase with the introduction of new regulatory requirements such as the LCR. Fender and Lewrick (2013) document an increased demand for high-quality collateral due to regulatory initiatives (e.g. collateral requirements in derivatives markets as well as Basel III liquidity and capital regulations) and discuss endogenous adjustments in the supply. Nagel (2016) argues that the liquidity premium of near-money assets such as US Treasury Bills does not only depend on the supply of liquid assets but rather on the opportunity cost of holding money, which is a function of the level of short-term interest rates. That is, if short-term interest rates are high, investors are willing to pay a larger liquidity premium for near-money assets than with low short-term interest rates. Finally, Nyborg and Östberg (2014) show that the

[2] The committed liquidity facility is part of the "alternative liquidity approaches" (ALA options) proposed by the Basel Committee on Banking Supervision (BCBS) and discussed in more detail in Section 6. Committed liquidity facilities have been implemented by the Reserve Bank of Australia and the South African Reserve Bank (see Bech and Keister (2014)).

demand for liquidity generally affects financial market activity. As funding stress rises, market participants sell relatively more liquid assets. Besides these empirical analyses, there exists a large theoretical literature on the interaction of the liquidity characteristics of an asset and its price. Among others, references are Kiyotaki and Moore (2005) and studies in the tradition of Lagos and Wright (2005), including Lagos (2010), Lagos and Rocheteau (2009), Rocheteau et al. (2015), and Williamson (2012).

Third, our paper is related to the literature dealing with the impact of haircuts on security prices. For instance, Ashcraft et al. (2010), Chapman et al. (2011), and Nyborg (2015) argue that haircuts applied in central bank open market operations affect the market price of securities and consequently investment decisions in the real economy, since the larger the haircut, the smaller the potential to use the collateral to borrow from the central bank. In this context, Bindseil and Papadia (2006) as well as Buiter and Sibert (2005) estimate the so-called "central bank eligibility premium" (CBEP). The CBEP is the yield differential between two identical securities where one security is eligible in central bank operations and the other one is not. The authors find little evidence for a significant CBEP but they argue that the premium is likely to be state-dependent. Bartolini, Hilton, Sundaresan and Tonetti (2010) show that there is a price differentiation in the US repo market by security type which varies significantly over time. The authors show that in times of stress, if reserves are scarce or if the central bank has a narrow collateral framework (i.e. only accepts few securities in its monetary policy operations), the price differentiation by security type is large, whereas if there is an ample supply of reserves or if market stress is not elevated, the differentiation is small.

3 Liquidity Coverage Ratio

The BCBS proposed the introduction of the LCR as an internationally harmonized liquidity standard in the aftermath of the global financial crisis as part of the Basel III reforms designed to enhance banks' resilience against short-term liquidity shocks (Basel Committee on Banking Supervision, 2013).[3] The LCR requires banks to hold an adequate stock of HQLA relative to their expected NCOF over a 30-day stress period. As a rule, NCOF must be covered by HQLA in the same currency. The LCR is calculated as the ratio of HQLA to NCOF and must be greater than or equal to one (see Equation 1).[4] The LCR was phased-in step-wise from 1 January 2015. That is, the LCR requirement was 60% in 2015 and it rises by ten percentage points every year until it reaches 100% in 2019.

$$\frac{HQLA}{NCOF} \geq 1 \tag{1}$$

[3]Note that the first LCR-proposal was published in December 2010 (Basel Committee on Banking Supervision, 2010).

[4]Note that during periods of financial stress, banks may use their stock of HQLA such that the LCR falls below 100%.

HQLA assets are subdivided into two categories: Level 1 and Level 2 assets. Level 1 assets include reserves, marketable government and central bank securities as well as securities issued by supranational organizations or multilateral development banks exhibiting the highest liquidity and credit quality.[5] The market value of Level 1 assets counts towards HQLA without being subject to a haircut, reflecting the assumption that these assets can be liquidated without significant losses in a short period of time even under severe stress. Consequently, these assets have the highest regulatory value.

Level 2 assets include the same types of securities as Level 1, however, their credit quality is lower.[6] Additionally, Level 2 assets include corporate debt securities issued by non-financial institutions and covered bonds. Level 2 assets count towards HQLA with a 15% haircut applied to the market value of the assets, reflecting the assumption that these assets might only be liquidated with an average loss of 15% in a severe stress scenario. Furthermore, the total stock of HQLA of a bank may contain no more than 40% Level 2 assets.[7] Assets that do not qualify as HQLA have no regulatory value under the LCR.

NCOF are the expected cash outflows minus the expected cash inflows over a 30-day stress scenario. Expected cash outflows are calculated by assigning weighting parameters to different bank liabilities. As a rule, the faster a liability is expected to run off, the higher its weighting parameter. Expected cash inflows capture a limited amount of contractual inflows from outstanding contracts within a 30-day period.

4 HQLA premium

In this section, we define the term "HQLA premium" and identify its determinants. To do so, we set up a simple model which is motivated by Bech and Keister (2014). Although the model is very simple, it is sufficiently rich to formulate hypotheses which we then assess empirically.

4.1 Definition

The HQLA premium is defined as the change in the yield to maturity (yield) spread between Level 1 and non-HQLA as well as Level 1 and Level 2 securities which can only be attributed to their differing regulatory treatment (see Figure 1). The HQLA premium is expected to be positive if the LCR is binding (permanently or temporarily) or binds in expectation, as banks are either forced to acquire additional HQLA securities, which drives up the price/lowers the yield for a given supply and for given NCOF, or banks are only willing to offer HQLA securities

[5]These securities are assigned a 0% risk weight under Basel II (see Basel Committee on Banking Supervision (1988)).

[6]These securities are assigned a 20% risk weight under Basel II (see Basel Committee on Banking Supervision (1988)).

[7]National authorities have the discretion to include additional security categories in the Level 2 definition, so-called "Level 2b" assets. A higher haircut is applied to Level 2b assets and the stock of HQLA may contain no more than 15% Level 2b assets.

at a higher price/lower yield. We expect the HQLA premium of Level 1 compared to non-HQLA securities to be larger than the HQLA premium for Level 1 compared to Level 2 securities. In the subsequent theoretical analysis, the focus is on the HQLA premium comparing Level 1 and non-HQLA securities.

Empirically, we observe a yield differentiation between Level 1, Level 2 and non-HQLA securities in the absence of the LCR. This yield differentiation can be attributed to the difference in the credit and liquidity risk of the corresponding securities and is documented in the empirical analysis below. With the LCR in place, and based on the intuition outlined above, we expect this yield spread to widen by the HQLA premium, with the size of the HQLA premium depending on several determinants studied below.

4.2 Theory

Consider an economy which is populated by a continuum of risk-neutral banks and a continuum of risk-neutral non-banks. Banks and non-banks are profit maximizing, operate in frictionless and perfectly competitive markets and take prices as given.

The model period is divided into two stages. In stage 1, banks are funded with deposits $\bar{D}$ and equity $\bar{E}$ which are initially held as reserves R. The funding structure is fixed for both stages. It is determined outside of the model and hence is exogenous for banks. In stage 2, a securities market opens and banks can re-adjust their portfolio using reserves. They can either purchase HQLA securities which are risk-free and earn the yield i_{HQLA} or purchase risky non-HQLA securities which earn the yield $i_{non\text{-}HQLA}$.[8] Non-HQLA securities are risky because they involve the risk of default and thus a payoff of zero. Banks can also keep reserves which are remunerated at i_r by the central bank. The central bank targets a risk-free interest rate which corresponds to the yield of HQLA securities.

All securities are initially held by non-banks.[9] The total stock of HQLA and non-HQLA securities is determined exogenously or can be thought of as being fixed in the short-run. The stock of non-HQLA securities is assumed to be large whereas the stock of HQLA securities is small. To simplify matters, we assume that non-banks can offer an unlimited amount of non-HQLA securities. The supply (demand) curve of both security types is assumed to be continuous and weakly decreasing (increasing) in the yield. In other words, non-banks are willing to supply securities if the yield on them is sufficiently low (i.e. the price is sufficiently high) and banks are willing to buy securities if the yield on them is sufficiently high (i.e. the price is sufficiently low).

Non-banks are only willing to supply HQLA securities at a yield which is smaller than or

[8]Note that the model's predictions remain unchanged using a broader definition of the non-HQLA position that would also include further asset classes such as loans.

[9]As documented in Arslanalp and Tsuda (2014) this is not an unrealistic assumption. They show that more than 80% of the outstanding volume of Swiss government debt was held by non-banks at the end of 2013. For other advanced economies, the fraction of government debt held by non-banks is of similar magnitude.

equal to $i_{HQLA}^{\textit{non-banks}}$ and which is lower than the yield at which non-banks are willing to supply non-HQLA securities, denoted as $i_{\textit{non-HQLA}}^{\textit{non-banks}}$. Non-banks are indifferent between supplying HQLA and non-HQLA securities if the yield spread is equal to τ. The yield spread τ represents the credit risk premium that ensures equal expected returns of holding either risky non-HQLA securities or risk-free HQLA securities.

In the absence of the LCR, banks are only willing to acquire HQLA securities if the yield is greater than or equal to i_{HQLA}^{banks} and, due to credit risk considerations, they are only willing to hold non-HQLA securities if the yield is greater than or equal to $i_{\textit{non-HQLA}}^{banks}$. Banks are indifferent between acquiring HQLA and non-HQLA securities if the yield spread is equal to τ. Banks strictly prefer to hold securities instead of reserves as long as $i_{HQLA} > i_r$. Below, we discuss possible equilibrium allocations with and without LCR as well as the interaction between monetary policy and the HQLA premium.

Proposition 1. *Without LCR, the pricing of HQLA securities and non-HQLA securities differs due to credit risk considerations. In equilibrium, it must hold that* $i_{HQLA} + \tau = i_{\textit{non-HQLA}}$.

Without LCR, banks and non-banks are indifferent between holding HQLA and non-HQLA securities if the above proposition applies. Any deviation from this relationship would immediately be arbitraged away. In equilibrium, banks' asset side has the following composition: reserve holdings are zero as long as $i_r < i_{HQLA}$, $HQLA \geq 0$, $\textit{non-HQLA} \geq 0$ and $HQLA + \textit{non-HQLA} = \bar{D} + \bar{E}$. Figure 2 shows a possible equilibrium allocation without LCR, where $i_r < i_{HQLA}$.

Introducing the LCR requires banks to cover NCOF with HQLA securities or reserves. Here, the only component of NCOF is represented by deposits $\bar{D}$ which are weighted by the LCR outflow parameter $\theta \leq 1$. Hence, the LCR restriction in our model can be expressed as follows:

$$\frac{HQLA + R}{\theta \bar{D}} \geq 1. \tag{2}$$

If the LCR is non-binding as banks already hold sufficient HQLA assets, no portfolio adjustment has to take place. If the LCR is binding, banks need to acquire additional HQLA securities or reserves and, as long as $i_r < i_{HQLA}$, banks strictly prefer to hold additional HQLA securities instead of reserves. There are two cases for the equilibrium allocation if the LCR is binding. Both cases are illustrated in Figure 3.

Case 1 represents an economy where the stock of HQLA is sufficiently large that banks can acquire additional HQLA securities without price impact. In this case, the HQLA demand curve crosses the HQLA supply curve in a region where the supply is elastic and hence $i_{\textit{non-HQLA}} - i_{HQLA} = \tau$ still holds in equilibrium.

Case 2 represents an economy where the stock of HQLA securities is insufficient relative to the required stock of HQLA securities. In this case, the HQLA demand curve crosses the HQLA supply curve in a region where the supply is inelastic and the market-clearing HQLA yield is lower than without LCR.

Proposition 2. *If the LCR is binding and if the supply of HQLA securities is not fully elastic, an HQLA premium μ is added to the existing yield differentiation between HQLA and non-HQLA securities. In equilibrium it must hold that $i_{non\text{-}HQLA} - i_{HQLA} = \tau + \mu$.*

In equilibrium, banks' asset side has the following composition: $R \geq 0$, $HQLA \geq 0$, $non\text{-}HQLA \geq 0$ and $R + HQLA + non\text{-}HQLA = \overline{D} + \overline{E}$ as well as the LCR condition $HQLA + R \geq \theta\overline{D}$ must hold. Note that in the equilibrium allocation of Case 2, shown in Figure 3, R must strictly be greater than zero, as the stock of HQLA securities is insufficient for all banks to fulfill the LCR with HQLA securities only.

The implications of Proposition 2 replicate nicely the argument by Stein (2013) that the HQLA premium is state dependent. That is, if HQLA securities are in ample supply, the HQLA premium is expected to be low, whereas if HQLA securities are scarce, the HQLA premium is expected to be high. Increasing the LCR requirement over time (LCR phase-in) or increasing the parameter θ requires banks to hold additional HQLA which may widen the HQLA premium further. Moreover, a change in the supply of HQLA also affects the HQLA premium.[10]

The equilibrium allocation of Case 2, shown in Figure 3, is relevant for central banks in three ways: First, remember that the central bank targets a risk-free rate (i.e. the yield of HQLA securities in the model). Without changing its monetary policy stance, i_{HQLA} can change due to the introduction of the LCR. Hence, central banks need to take the HQLA premium into consideration when targeting a certain risk-free rate. Second, in case of insufficient HQLA securities, central banks may be forced to operate with a larger balance sheet than they would in an environment without LCR as they face additional demand for reserves from banks.[11] Third, if the central bank reduces the risk-free rate, and hence the yield on HQLA securities, to the level of the interest rate it pays on reserves (essentially a floor system of monetary policy implementation), banks become indifferent between holding reserves and HQLA securities. In this case, the HQLA premium is zero, irrespective of whether HQLA securities are scarce (see Figure 4). This is in line with Nagel (2016) who documents that the liquidity premium of near-money assets such as US Treasury Bills decreases with lower short-term interest rates and thus lower opportunity cost of holding money (here reserves).

Proposition 3. *If $i_{HQLA} = i_r$, the HQLA premium μ is zero as banks are indifferent between*

[10] Note that in practice, $\bar{E}$ and $\bar{D}$ are not determined exogenously. In order to reduce the required holdings of HQLA, banks could shrink their balance sheet by reducing their deposits and selling non-HQLA securities (de-leveraging). Another way to reduce the required holdings of HQLA is to restructure the banks' liabilities towards positions with a lower outflow parameter. Both strategies reduce the demand for HQLA and thus the HQLA premium. Note that the model's predictions remain unchanged with regard to an increase of the balance sheet size even if $\bar{E}$ and $\bar{D}$ are not determined exogenously.

[11] The second implication is not a direct outcome of the model as banks hold their endowment in the form of reserves and as long as $\bar{E} \geq 0$ and $\theta \leq 1$ there are always sufficient reserves to ensure that every bank is able to fulfill its LCR. In reality, due to leverage, the consolidated balance sheet of the banking system is only partially covered by reserves.

holding reserves or HQLA securities in order to fulfill the LCR requirement.

4.3 Hypotheses

Based on the theoretical considerations above, we can derive the following three hypotheses, which we subsequently assess empirically.

Hypothesis 1: Without LCR, the pricing of HQLA securities and non-HQLA securities differs due to credit and liquidity risk considerations.

Hypothesis 2: If the LCR is a binding constraint and if the supply of HQLA securities is not fully elastic, an HQLA premium is added to the existing yield differentiation between HQLA and non-HQLA. The size of the HQLA premium depends on the additional HQLA demand caused by the LCR, the elasticity of the HQLA supply and the degree to which banks can reduce their NCOF.

Hypothesis 3: If the yield on HQLA securities is equal to the interest rate the central bank pays on reserves and banks are holding excess reserves the HQLA premium is zero as banks are indifferent between holding reserves and HQLA securities in order to fulfill the LCR.

5 Empirical analysis

This section empirically assesses the three hypotheses outlined in the previous section. To do so, we make use of the change in the liquidity regulation in Switzerland which serves as a quasi-natural experiment and allows us to quantify the HQLA premium. The following paragraphs are structured as follows: First, we discuss the former liquidity regulation and highlight the main differences vis-à-vis the LCR. Second, we describe the dataset used for our empirical analysis. Third, we provide descriptive statistics on our data. Fourth, we describe our empirical strategy and discuss the results. Finally, we subject our regression analysis to several robustness checks.

5.1 Institutional background

In Switzerland, banks were already subject to liquidity requirements before the introduction of the LCR (Federal Council, 2003). The former liquidity regulation, which dated back to 1988, required banks to cover at least 33% of specific short-term liabilities with liquid assets, the equivalent of HQLA under the LCR. Liquid assets were eligible for the fulfillment of the liquidity regulation uniformly and without haircut. Among others, securities eligible in SNB repo transactions were deemed to be liquid assets.

From a methodological perspective, the LCR and the former liquidity regulation are fairly similar, as both regulations require banks to hold a certain stock of liquid assets to cover potential liquidity outflows. However, the former liquidity regulation is considered as less stringent as it was not parameterized to the stress periods experienced during the financial crisis, allowed for currency mismatches between outflows and liquid assets and was not internationally harmonized (FINMA, 2014).[12]

In Switzerland, the former liquidity regulation was replaced upon publication of the LCR legislative principles by the Swiss Federal Council on 25 June 2014 (Federal Council, 2014) and the LCR eventually came into effect on 1 January 2015. On 7 July 2014, the Swiss Financial Market Supervision Authority (FINMA) published detailed information on the legislative principles and a list published by the SNB was available with a classification of all SNB-eligible securities under the new liquidity regulation, defining which securities belong in which category: Level 1, Level 2, or non-HQLA (FINMA, 2014).[13] A comprehensive list covering virtually all CHF-denominated HQLA securities has thus been publically available and became widely used by banks to manage their stock of HQLA.[14] Throughout the paper we shall be referring to the FINMA's 7 July 2014 announcement as the "regulatory change", since we believe that the 7 July 2014 has attracted more attention among banks than the publication of the legislative principles.[15]

Under the LCR, CHF-denominated securities that formerly qualified as liquid assets are affected in one of the following three ways: First, the regulatory treatment of a security remains unchanged if it qualifies as a Level 1 asset; such assets count towards the liquidity buffer with 100% of their market value. Second, a security is subject to a regulatory downgrade if it qualifies as a Level 2 asset. The regulatory treatment of Level 2 assets differs from that under the former liquidity regulation as Level 2 assets may only be counted towards HQLA with a 15% haircut and the total stock of HQLA may contain no more than 40% Level 2 assets (cap). Third, a security no longer has any regulatory value under the LCR if it qualifies as non-HQLA; it is

[12]Since mid-2010, an additional liquidity regime, very similar to the LCR, has been introduced for systemically important banks in Switzerland. Compared to the LCR, the stress scenario underlying the estimates for the outflow parameter is more severe in the Swiss liquidity regime. However, the definition of the liquidity buffer is broader, less focused on government bonds and most importantly not CHF specific (see Nixon, Portes and Danthine (2013)).

[13]This list was available as of 2 May 2014, already. With the publication of the detailed information on the legislative principles, a reference to this list was made by FINMA and the classification became widely used by market participants. Moreover, a press release by the SNB as of 7 July 2014 also referred to this list.

[14]This list was published in light of a change in the SNB's collateral policy. With this adjustment, non-HQLA securities were excluded from the list of SNB-eligible securities, as of 1 January 2015. By aligning its collateral policy to the LCR, the SNB ensured that collateral eligible in its monetary policy operations continues to be viewed as a liquid asset from a regulatory perspective (Swiss National Bank, 2014). For non-HQLA securities, the HQLA premium might also include a CBEP. In Switzerland, the CBEP is currently expected to be very low or close to zero for CHF-denominated securities for several reasons. As a result of the SNB's unconventional measures, the banking system is currently operating in a structural liquidity surplus and thus not dependent on central bank funding. Given the banks' liquidity situation, the SNB discontinued its liquidity-providing open market operations in May 2010 and is currently only operating its "liquidity-shortage financing facility" – an instrument that has been used rarely in previous years (see SNB accountability reports). Furthermore, as a result of the banks' liquidity situation, funding stress in the Swiss banking system is currently at low levels (see, for example, the Swiss franc Libor-OIS spread).

[15]Note that our results hold independently of the choice of the regulatory treatment date (see robustness checks).

therefore subject to regulatory exclusion.[16]

5.2 Data

The dataset used in the analysis comprises securities which were SNB-eligible in 2014 and hence were deemed to be liquid assets under the former Swiss liquidity regulation.[17] SNB-eligible securities are homogenous securities that fulfill strict requirements with regard to the credit and liquidity quality. Eligible securities are fixed-rate, floating-rate or zero-coupon interest-bearing securities denominated in CHF as well as EUR, US Dollar, Pound Sterling, Danish Krone, Swedish Krona and Norwegian Krone. These must be issued by central banks, public-sector entities, international or supranational institutions or private-sector entities (including covered bonds and Swiss Pfandbriefe). As a rule, all eligible securities must be marketable and traded on a recognized stock exchange or a representative market that publishes price data on a regular basis.

Standards with respect to the rating and liquidity of securities are high. Eligible securities must have a minimum long-term rating of AA- (where the second-best rating of Standard & Poor's, Moody's and Fitch is decisive) and a volume at issuance equivalent to at least CHF 1 billion (bn) for non-CHF-denominated securities and CHF 100 million (mn) for securities denominated in CHF.[18] By the end of 2014, about 2,800 different securities with a combined worth of CHF 9,650 bn were SNB-eligible, of which CHF 7,835 bn (81.2%) were classified as Level 1 securities, CHF 1,580 bn as Level 2 securities (16.4%) and 235 bn as non-HQLA securities (2.4%). As the list of SNB-eligible securities is subject to daily modifications due to new issues, redemptions or exclusions, small fluctuations in the overall volume do occur.

To quantify the HQLA premium, we collected daily price information (mid prices) as well as further ISIN specific characteristics for all SNB-eligible securities from Bloomberg. To check whether the empirical analysis is not relying on theoretical security prices calculated by Bloomberg, we inspected Bloomberg's pricing source ex-post (i.e. in 2015). For the vast majority of the securities we use, the price information we found are based on actual transactions or executable quotes.[19] The HQLA attribute is based on SNB's HQLA classification.

[16] Consider, for instance, a bank that holds three types of assets, each with a value of one and all of which qualify as liquid assets. Under the former liquidity regulation, the stock of liquid assets would have amounted to three. Now assume that the three types of assets correspond to the HQLA categories such that there is one unit of Level 1 assets, one unit of Level 2 assets and one unit of non-HQLA assets. Under the LCR, the stock of HQLA would amount to 1.67. This is because one unit of Level 1 assets counts in full. Due to the 15% haircut and the 40% cap, only 0.67 of the Level 2 assets qualifies as HQLA. The one unit of non-HQLA assets no longer counts towards HQLA, at all.

[17] This subsection gives a brief overview of the SNB's collateral framework and draws on Swiss National Bank (2015). For more details, see, for example, Fuhrer, Guggenheim and Schumacher (2016).

[18] Note that until 2015, the rating threshold was A for securities denominated in CHF.

[19] In the ex-post analysis, executable prices from market participants (quoted bid and ask prices as well as executable volumes) or prices from stock exchanges are available for about 99% of all SNB-eligible securities denominated in EUR and CHF considered in the empirical analysis. Compared to ECB-eligible securities, this ratio is high. Based on a real-time analysis, Nyborg (2015) shows that around 77% of all ECB-eligible securities have only theoretical prices (17% if counted by volume). Potential reasons for this large difference may include:

Given our focus on the regulatory change, the following adjustments to the set of SNB-eligible securities have been made. First, only securities denominated in EUR and CHF are considered, for three reasons: (i) EUR and CHF securities fulfill the crucial parallel trend assumption for our econometric approach to measuring the impact of the regulatory change (discussed below); (ii) only securities denominated in these two currencies span all HQLA attributes (Level 1, Level 2 and non-HQLA) – a precondition for the empirical analysis; and (iii) roughly 80% of all SNB-eligible securities are denominated in these two currencies. With these modifications, our dataset contains 2,756 different securities for the year 2014. Second, to ensure a fixed dataset, only securities that were SNB-eligible throughout the observation period are considered. Securities that were issued during the observation period are therefore not part of the data sample. Moreover, we exclude securities that mature before 1 February 2015, since they do not affect the LCR and should in turn not be affected by the new regulation.[20] This reduces the sample size to 1,807 securities. Third, we exclude 27 securities for which the HQLA attribute has changed during the observation period.[21] Fourth, we only consider zero or fixed-coupon securities and therefore excluded 120 securities with variable coupon payments.[22] Consequently, the final dataset comprises 1,660 securities and includes daily price information for each security for the year 2014. Moreover, for each security the currency of denomination, maturity, coupon, HQLA attribute, volume at issuance and daily yield to maturity are known.[23]

5.3 Descriptive statistics

Below, we present descriptive statistics to give an overview of the dataset used in the empirical analysis. Furthermore, the descriptive statistics provide valuable insights for *Hypothesis 1*.

Number of securities: Table 1 shows the distribution of the securities according to currency of denomination, securities' duration (Macaulay duration) and HQLA attribute. The number of securities denominated in CHF and EUR are roughly balanced, with 778 securities denominated in CHF and 848 securities denominated in EUR. The distribution of Level 1, Level 2 and non-HQLA securities by count is 48%, 46% and 6% (by volume 81%, 17% and 2%) for EUR-denominated securities and 26%, 55% and 19% (by volume 38%, 47% and 15%) for CHF-denominated securities, respectively. The lower share of Level 1 securities denominated in CHF

(i) the fact that the SNB only considers marketable securities, for which prices are published on a regular basis; (ii) the fact that the SNB only considers high-quality and liquid securities whereas the ECB collateral framework allows for a broader range of securities; (iii) the number of eligible securities, which is relatively small in the case of the SNB (around 2,800 securities) and large in the case of the ECB (around 35,000 securities) as documented by Nyborg (2015).

[20] Securities that mature within 30 days affect the stock of HQLA and the NCOF to the same extent and thus there is no significant LCR impact.

[21] The HQLA classification for those securities was revised between July 2014 and December 2014 due to re-specifications with respect to HQLA requirements by the regulatory authority.

[22] These are floating rate notes, variable rate notes as well as inflation protected bonds.

[23] Throughout the paper, we analyze security yields and not prices. The yield accounts for the security's current market price, the coupon and the residual maturity.

evaluated by count and volume reflects the fact that, compared to the euro area, Switzerland has relatively few government bonds outstanding. The low share of EUR denominated Level 1 securities when evaluated by count compared to the share when evaluated by outstanding volume is due to the fact that the issuance volume of Level 1 securities is larger than for Level 2 or non-HQLA securities.

Credit quality: Figure 5 and 6 show the distribution of securities according to their second best credit rating (as defined above) for Level 1, Level 2 and non-HQLA securities denominated in CHF and EUR. It confirms that the different HQLA categories have different credit qualities. In particular, there is a distinct difference in the average credit quality of Level 1 and non-HQLA securities which is prevalent for securities denominated in CHF as well as EUR. For both currencies, most Level 1 and Level 2 securities have a “AAA” rating whereas most non-HQLA securities have a “AA-” rating. Overall, the credit quality of the securities in our dataset is very high.

Outstanding volume: The total outstanding volume of EUR-denominated securities amounts to EUR 3,870 bn and is considerably larger than the outstanding volume of CHF-denominated securities, which amounts to CHF 326 bn (see Table 1). Figure 7 shows the average outstanding volume for Level 1, Level 2 and non-HQLA securities by currency of denomination. On average, EUR-denominated securities have a substantially higher outstanding volume than CHF-denominated securities.[24] Moreover, the figure shows that, irrespective of the currency of denomination, Level 1 securities have the highest outstanding volume followed by Level 2 and non-HQLA securities.

Price variation: To analyze the price variation of security prices, we calculated the standard deviation of each security’s daily price changes as well as the maximum price decline within a 30-day window for each security in the observation period 9 January 2014 to 17 December 2014. The second measure follows closely the 30-day LCR stress scenario (Basel Committee on Banking Supervision (2013), para 52). The findings of the analysis of price variation are as follows: First, price changes were fairly moderate in 2014. Moreover, as yields of securities were mostly decreasing over the sample period, prices mostly increased and hence the observed price declines are fairly small (Table 2). Second, the price variation is generally increasing in the duration of a security which confirms that duration is a good proxy for the variability of security prices (Table 3). Third, price changes of Level 1 (Level 2) securities are somewhat smaller than for Level 2 (non-HQLA) securities. Fourth, whether securities are denominated in EUR or CHF seems to play a minor role for the price variation.

[24]This large difference between CHF and EUR securities is, at least in part, due to the fact that the SNB-eligible securities must have a volume at issuance equivalent to CHF 1 bn if denominated in foreign currencies and CHF 100 mn if denominated in CHF.

Yield curves: Figure 8 and Table 4 show empirical yield curves for the different HQLA attributes in both currencies as of 7 July 2014. For both currencies the yield curves have fairly standard shapes. However, they differ with regard to their level, slope and curvature. Regardless of the currency of denomination or the duration, Level 1 securities have the lowest yields, followed by Level 2 securities. Non-HQLA securities exhibit the highest yields.

Yields and credit spreads: Figure 9 and 10 show yields of Level 1, Level 2 and non-HQLA securities in EUR and CHF for the year 2014. Both figures display generic yields for securities with a constant duration of two, three and four years respectively.[25] Overall, we observe a negative trend in yields for all HQLA attributes and both currencies but the decline in yields is more pronounced for EUR-denominated securities.

The figures also reveal the HQLA spreads, which are defined as the difference between the yields of non-HQLA and Level 1 securities (Level 2 and Level 1 securities) denominated in CHF and EUR. The yield spread between EUR-denominated non-HQLA and Level 1 (Level 2 and Level 1) securities is about 45 bps (15 bps). For CHF-denominated securities, the respective spreads are somewhat lower at 25 bps (10 bps). The yield spread between non-HQLA and Level 1 securities denominated in CHF started to increase in September/October 2014 by up to 10 bps. This is at odds with the overall trend in yields for the period we examine and is an indication for the potential re-pricing due to the HQLA premium.

Summary: The descriptive analysis indicates that Level 1 securities have the highest credit quality and the highest issuance volume, followed by Level 2 and non-HQLA securities. Moreover, the analysis of the price variation suggests that it is reasonable to assign the lowest haircut to Level 1 assets, followed by Level 2 and non-HQLA assets. These differing credit and liquidity characteristics are reflected in a yield differentiation, which provides evidence for *Hypothesis 1.* Finally, yields of non-HQLA securities denominated in CHF increased after the regulatory change, which is not observable for their EUR counterparts.

5.4 Methodology

To exploit the impact of the regulatory change on security yields, we rely on a difference-in-difference analysis. With the difference-in-difference approach, we study the impact of the regulatory change using two different groups, namely a treated group (CHF-denominated securities) and a non-treated group (EUR-denominated securities), where the non-treated group is not affected by the regulatory change and thus serves as a control group.

Since the regulatory change is only relevant for Swiss banks, which are required to fulfill their

[25] Generic yields with a constant duration are calculated via the daily estimation of a yield curve for Level 1, Level 2 and non-HQLA securities in EUR and CHF using polynomic interpolation (with five degrees).

LCR requirement predominantly with CHF-denominated HQLA, a HQLA premium should be priced in for securities denominated in CHF but not for those denominated in EUR.[26] As the LCR legislative principles in the EU were published on 10 October 2014, our control group should therefore be unaffected by the regulatory change in the EU up to this date.[27]

In order to ensure that the announcement of the ECB's covered bond purchase programme on 4 September 2014 does not bias our results by decreasing the yield of EUR-denominated covered bonds and thus the Level 2 control group which could lead to an overestimation of the HQLA premium, we exclude Level 2 securities from the baseline analysis (see Figure 11). Consequently, our empirical analysis lasts from 9 January 2014 to 9 October 2014 and contains Level 1 and non-HQLA securities, only. The period before the regulatory change covers the period from 9 January to 6 July (pre-period sample) and the period after the regulatory change lasts from 7 July until 9 October 2014 (post-period sample).

Besides the prerequisite that the regulatory change is only relevant for the treated group and leaves the control group unaffected, the other crucial assumption for the validity of our difference-in-difference analysis is that the treated and the control group behave similarly in the absence of the treatment (parallel trend assumption). Even though we can never test this assumption perfectly, the following three indicators highlight that this is the case for the treated and the control group under examination. First, the dataset is characterized by very homogenous securities denominated in CHF and EUR. Besides their similar credit and liquidity qualities, all assets considered in the analysis were SNB-eligible and hence automatically qualified as liquid assets under the former Swiss liquidity regulation. Second, the descriptive analysis suggests that the parallel trend assumption for EUR- and CHF-denominated securities is valid before the regulatory change. Figure 12 shows that HQLA spreads in EUR and CHF behaved fairly similar prior to the regulatory change, which is no longer the case afterwards. Third, several regression analyses for time periods without regulatory treatment (hereinafter "placebo regression") with fictional regulatory changes in the pre-period sample fail to reject the parallel trend assumption (see detailed discussion in the subsection Robustness).[28] Overall, this quasi-natural experiment fulfils the crucial difference-in-difference assumption that, disregarding the treatment, the HQLA spreads in the treated and the non-treated groups behaved very similar.

[26]In order to take into account the potential shortage of HQLA securities denominated in CHF, the Swiss regulator has opted for the "alternative liquidity approaches" (ALA option two or three) within the Basel III LCR framework. Option two allows banks with adequate foreign exchange management to cover a fraction of NCOF with HQLA denominated in pre-defined foreign currencies. The impact of the regulatory change on yields of EUR-denominated HQLA securities should, however, be negligible, since the volume of EUR-denominated HQLA securities is large compared to the volume of NCOF of Swiss banks that can potentially be covered by HQLA denominated in EUR.

[27]Note that if the regulatory change was partially anticipated, this would lead to an underestimation of the HQLA premium and we discuss this in more detail, below.

[28]Among other things, we believe that the closeness of the HQLA spreads can, at least in part, be attributed to the highly integrated nature of the economies in question and to the minimum exchange rate that has been in place throughout 2014.

5.5 Econometric specification

For the difference-in-difference analysis we follow the recommendations by Bertrand, Duflo and Mullainathan (2004) as well as Degryse, Kim and Ongena (2009) and proceed as follows: First, the dataset is divided into two sub-periods, namely a period before and a period after the regulatory change. The pre-period sample runs from 9 January 2014 to 6 July 2014 and the post-period sample from 7 July 2014 to 9 October 2014. Second, we calculate average yields of each individual security i for the pre- and post-period samples ($\bar{y}_i^{\text{Pre}}$, $\bar{y}_i^{\text{Post}}$). Third, the change between the two average yields ($(\bar{y}^{\text{Post}} - \bar{y}^{\text{Pre}})_i$) is calculated for each individual security. Fourth, we run a regression of the individual yield changes on a constant and a dummy variable for non-HQLA securities (non-HQLA$_i$), while controlling for the currency of denomination by using a dummy variable for all securities denominated in CHF (CHF$_i$). Additionally, we include an interaction term for non-HQLA securities denominated in CHF (CHF x non-HQLA$_i$) which represents the HQLA premium and thus the variable of interest. Finally, as securities with different durations are included in the regression, we control for the term structure of interest rates using the securities' duration. As the EUR and CHF term structure of interest rates are not identical (see Figure 8), we control for the non-linear term structure of the two currencies individually by including the securities' duration (duration$_i^{CHF}$, duration$_i^{EUR}$) and the securities' squared duration (duration$^{2CHF}_i$, duration$^{2EUR}_i$) as of 7 July 2014.[29] Table 5 exemplifies the use of dummy variables in the regression specification.

In this regression specification, which eliminates the time series dimension of the dataset by calculating average yields for each security pre and post the regulatory treatment, the regression standard errors do not suffer from a potential serial autocorrelation problem as documented by Bertrand et al. (2004).[30] More formally, we can write the OLS regression model as outlined in Equation 3.

$$\begin{aligned}(\bar{y}^{\text{Post}} - \bar{y}^{\text{Pre}})_i &= \alpha + \beta_1 \text{ non-HQLA}_i + \beta_2 \text{ CHF}_i \\ &+ \beta_3 \text{ CHF x non-HQLA}_i + \beta_4 \text{ duration}_i^{CHF} \\ + \beta_5 \text{ duration}^{2CHF}_i &+ \beta_6 \text{ duration}_i^{EUR} + \beta_7 \text{ duration}^{2EUR}_i + \epsilon_i.\end{aligned} \tag{3}$$

The general development of yields is captured by the constant. Since we control for the add-on of non-HQLA securities as well as the currency of denomination, the constant represents the development of EUR-denominated Level 1 yields. By controlling for the add-on of non-HQLA securities denominated in CHF, the CHF$_i$ coefficient represents the development of CHF Level 1

[29]Note that the regression results are quantitatively unaffected when using different specifications to control for the term structure of interest rates or the duration date (see Table 7).

[30]Among others, the advantage of such a methodology is described by Degryse et al. (2009) and applied by Cerqueiro, Ongena and Roszbach (2016).

yields vis-à-vis EUR Level 1 yields. Moreover, since Level 1 securities denominated in CHF are not affected by the regulatory change (i.e. their regulatory treatment remains unchanged), the CHF_i coefficient captures only yield changes that affect all securities denominated in CHF equally (i.e. a general change in CHF yields). Consequently, the impact of the regulatory change and hence the HQLA premium is captured by the coefficient of the CHF x non-HQLA_i dummy variable, which we expect to be positive and statistically significant.

5.6 Results

The regression results of our baseline analysis are displayed in Table 6, Column (1). The regression coefficient for non-HQLA securities denominated in CHF (CHF x non-HQLA_i) is around 0.04 and is significantly different from zero. Thus, yields of CHF securities which are subject to a regulatory downgrade increased by 4 bps relative to the corresponding EUR non-HQLA securities. The coefficient has the expected positive sign and is of statistical significance. However, with 4 bps, the magnitude of the HQLA premium is rather small.

The negative trend in EUR Level 1 yields is reflected by the negative coefficient of the constant. The yield decrease for EUR non-HQLA securities is more pronounced than for EUR Level 1 assets, as is indicated by the negative and statistically significant coefficient. The coefficient of the dummy variable for securities denominated in CHF is positive and statistically significant. This implies that the average yield decrease of CHF-denominated Level 1 securities is less pronounced than the average yield decrease of EUR-denominated Level 1 securities. Finally, the slope (duration_i) and the curvature coefficients (duration_i^2) are statistically significant for both currencies (see Table 7, Column (1)). Overall, the model fit is relatively good with an adjusted R^2 of 0.86.[31]

5.7 Robustness

Below, we discuss several robustness checks with respect to both the specification of our model and to the data sampling. Overall, we find that the results from the baseline regression are confirmed.

Outstanding volume: In Table 6, Column (2), we assess whether our findings depend on securities with a relatively small outstanding volume. To do so, we only consider CHF securities with an outstanding volume of more than CHF 175 mn. This is, we exclude the least liquid 25% of all CHF denominated securities from the dataset (i.e. 87 securities).[32] In this regression specification, the coefficient for non-HQLA securities denominated in CHF is about

[31]This is mainly due to the inclusion of the securities' duration, which explains a significant part of the variation of yield changes. Note that without considering the securities' residual maturities, the adjusted R^2 is 0.28.

[32]Of the excluded 87 securities, there are 55 Level 1 and 32 non-HQLA securities.

4.5 bps which suggests that the HQLA premium may be slightly larger for more liquid securities.

Swiss issuers: Table 6, Column (3) shows the baseline regression specification, using only CHF-denominated securities of Swiss issuers in the treatment group. The intuition behind this regression specification is that the HQLA premium might be more pronounced for domestic securities due to a potential home bias. Also with this regression specification, the HQLA premium is about 4.5 bps and thus slightly larger than in the baseline regression.

Regulatory change: In order to test the robustness of our regression specification, we repeat the regression analysis using the announcement of the LCR by the Swiss Federal Council as the date of the regulatory change. When using the 25 June 2014 instead of the 7 July 2014 as the treatment date, our results remain broadly unchanged (see Table 6, Column (4)).

Placebo regression: In order to test the validity of the difference-in-difference approach, we repeat the regression analysis for a period without regulatory treatment.[33] In the absence of the regulatory treatment, we expect the treatment coefficients to be close to zero and statistically insignificant, confirming that, in absence of the treatment, the control group and the treatment group are indeed very similar. Table 6, Column (5) reports the results of the placebo regression when using the observation period 9 January to 6 March 2014, with a fictional date for the regulatory change on 5 February 2014. The treatment group and the control group are indeed very similar, as the non-HQLA coefficient for securities in CHF (CHF x non-HQLA$_i$) is close to zero and statistically insignificant. The development of non-HQLA securities denominated in CHF is therefore well captured by the general non-HQLA$_i$ dummy.

Shorter post-period sample: In our baseline regression, we end our post-period sample on 9 October 2014, but exclude Level 2 securities to ensure that our control group is unaffected by the announcement of the ECB covered bond purchase programme on 4 September 2014. Table 6, Column (6) shows the regression results using a post-period sample ending on 3 September 2014. This allows us to run a regression analysis which also includes Level 2 securities (see Table 8 for the specification of the dummy variables). With this regression specification, the HQLA premium for Level 2 and non-HQLA securities is about 1.5 bps. The coefficient for Level 2 securities denominated in CHF is statistically significant, whereas the coefficient for non-HQLA securities is not. In our view, the smaller HQLA premium for non-HQLA securities compared to our baseline regression is due to the fact that banks did not adjust their portfolios immediately after the regulatory change but rather gradually over time which is confirmed by anecdotal evidence from market participants.

[33] Note that we have tested several placebo regression specifications which all fail to reject the parallel trend assumption. For simplicity, we just display one possible regression specification.

Term structure specification: In order to test whether our results depend on the term structure specification, the choice of the securities' duration date or whether we control for the securities duration or the residual maturity, several alternative term structure specifications have been tested. Table 7 reports the corresponding regression results as well as our baseline results (illustrated in Column (1)). Overall, we find no qualitative discrepancies from our baseline results irrespective of the specification chosen. Column (2) reports the results when using the securities' residual maturity instead of its duration. Column (3) displays the regression results when using the securities' residual maturity as well as the coupon. Columns (4) and (5) use the information on the securities' duration as of 9 May respectively 10 October 2014 instead of 7 July 2014. Finally, Column (6) reports the regression results when including a cubic term to control for the term structure into our baseline regression model.

HQLA spreads: In order to test whether our findings are robust irrespective of the econometric approach chosen, we repeat our analysis and use daily HQLA spreads ($spread_{j,t}$) between generic non-HQLA and Level 1 yields for various durations (j), ranging from one to ten years calculated for securities denominated in CHF and EUR (see also Figure 12). These generic spreads are regressed on a CHF dummy ($\text{CHF}_{j,t}$), a post-period sample dummy ($\text{Post}_{j,t}$) as well as the corresponding interaction term ($\text{Post x CHF}_{j,t}$), i.e. a dummy variable for CHF securities after the regulatory treatment, which represents the HQLA premium and is thus the variable of interest. More formally, we can write the OLS regression model as outlined in Equation 4.

$$\text{spread}_{j,t} = \alpha_j \; + \; \beta_1 \text{ Post}_{j,t} \; + \; \beta_2 \text{ CHF}_{j,t} \; + \; \beta_3 \text{ Post x CHF }_{j,t} \; + \; \epsilon_{j,t}. \tag{4}$$

The regression results reported in Table 9 show again a positive and statistically significant HQLA premium which is in the order of 6 bps and thus comparable to our baseline results.[34]

HQLA spreads in CHF: Another econometric approach is to focus on securities denominated in CHF, only. This approach does therefore not rely on EUR denominated securities serving as a control group. To do so, we regress HQLA spreads between non-HQLA and Level 1 securities denominated in CHF with generic durations of one to ten years (see Figure 10) on a post-period sample dummy which represents the HQLA premium and is thus the variable of interest as well as the CBOE Volatility Index (VIX) which is expected to approximate yield spreads and thus is a proxy for our control group. Table 10 shows the corresponding regression results. Again,

[34]Note that we have also conducted a regression analysis using daily security yields with dummy variables specified as outline in our baseline regression, however, interacted with a post-period sample dummy and using time and ISIN fixed effects. Using such a methodology, which is for instance applied by Lambert, Noth and Schwer (2015), yields again to a positive and statistically significant HQLA premium.

we find a positive and statistically significant HQLA premium in the order of about 2 bps. Therefore, also the analysis relying on CHF denominated securities only provides evidence for a small but positive and statistically significant HQLA premium.

6 Discussion of results

The empirical results provide evidence for the existence of a HQLA premium of a rather small magnitude. This is in line with *Hypothesis 3* of the theoretical considerations when taking into account the current monetary policy environment in Switzerland. Subsequently, we discuss our empirical findings in more detail.

Monetary policy environment: As a result of the unconventional measures taken by the SNB since 2008, and in particular due to foreign currency purchases since 2009, the banking system currently holds large excess reserves and CHF interest rates are close to the rate the SNB pays on reserves (until 2015, the interest rate on reserves was 0%). At the end of 2015, the reserve holdings of banks were approximately 95 times as high as they were before the financial crisis. In contrast to the kind of quantitative easing that creates reserves by purchasing HQLA securities in a given central bank's domestic currency (thereby leaving the stock of HQLA unchanged), the SNB has created reserves by purchasing foreign assets. In doing so, the SNB has considerably increased the stock of Level 1 securities denominated in CHF.[35] The theoretical considerations of *Hypothesis 3* suggest that in such a monetary policy environment, the HQLA premium is expected to be small or close to zero. This corresponds to the findings in our empirical analysis.

Alternative Liquidity Approaches (ALA): The crucial question that arises from these considerations is whether, and to what extent, the HQLA premium would increase under normal monetary policy conditions. In Switzerland, the regulator has stated that there is a structural shortage of HQLA securities denominated in CHF given the HQLA needs of the banking system. This is due to the small capital market and in particular the low volume of government debt outstanding. In the absence of any additional mitigating factors, we would expect to encounter an economically significant HQLA premium under pre-crisis monetary policy conditions (see *Hypothesis 2*).

The BCBS acknowledges that there are jurisdictions with a structural shortage of HQLA, and for these jurisdictions, the BCBS allows for the application of so-called ALA options. There are three different ALA options and all three are intended to widen the set of securities that count towards HQLA (see Basel Committee on Banking Supervision (2013) for a detailed description

[35] As a mirror image of the additional reserve holdings by banks, the foreign currency purchases have also created additional liabilities. An analysis of the consolidated balance sheet of the banking system shows that it is primarily retail and wholesale deposits that have increased in response to the foreign currency purchases of the SNB. As the outflow parameters that are assigned to those liabilities are rather small, foreign currency purchases have increased the banking system's LCR.

of the ALA options). In view of the structural shortage of HQLA securities denominated in CHF, the regulator in Switzerland permits Swiss banks to apply either ALA option two or three in order to fulfill the LCR. Option two allows banks with an adequate foreign exchange management to cover a fraction of NCOF denominated in CHF with HQLA denominated in pre-defined foreign currencies. Option three relaxes the 40% Level 2 securities cap. Theoretically, both ALA options should reduce the HQLA premium by increasing the supply of HQLA securities (a rightward shift of the HQLA supply curve in our theoretical model).

Methodology: In the econometric specification used, the exogeneity of the announcement of the regulatory change and the validity of the control group are key. In this respect, our empirical analysis underestimates the HQLA premium if market participants did not price in the HQLA premium immediately after the regulatory change, but rather gradually over time. Moreover, we would also underestimate the HQLA premium if the regulatory change was anticipated either in Switzerland or in the euro area.[36] Finally, our results are robust to other regulatory reforms, such as the Basel III Leverage Ratio, as long as they affect security prices in the treated as well as in the control group.[37]

7 Policy implications

In the following, we discuss potential policy implications of our findings which are relevant for central banks, market participants and regulators in general.

Monetary policy: A non-zero HQLA premium affects the equilibrium relationship between asset prices and central bank policy rates (see Bech and Keister (2014) as well as BIS Committee on the Global Financial System (2015)). Thus, central banks need to take the HQLA premium into account and target a different level for their policy rates in order to establish the desired monetary conditions.[38] If the HQLA premium is also a function of the availability of HQLA, establishing the same monetary conditions will require adjustments of the policy rate in response to changes of the HQLA premium. Moreover, if there is a scarcity of HQLA securities, banks' demand for reserves will increase in order to ensure compliance with the LCR. This, in turn, implies that central banks may be forced to operate with larger balance sheets than they would without the LCR (see Debelle (2011)). Finally, the choice of how to exit unconventional mone-

[36]Note that the first draft of the Basel III LCR rulebook was published in 2010 (Basel Committee on Banking Supervision, 2010). This may have led banks to anticipate the regulatory change, which in turn may have caused a re-adjustment of banks' securities portfolios and a re-pricing of securities prior to the regulatory change.

[37]For more details on the interaction and potential amplifying effects between different regulatory initiatives, see BIS Committee on the Global Financial System (2015).

[38]At the level of 4 bps and in view of the usual model uncertainties for central banks to target a specific policy rate, the HQLA premium is currently of minor importance.

tary policy might be affected by a potential scarcity of HQLA and a non-zero HQLA premium (see Berentsen et al. (2015)).

Bond markets: A non-zero HQLA premium suggests that conditions on the primary bond market change in response to the introduction of the LCR. Specifically, funding costs for issuers of non-HQLA securities increase relative to funding costs for issuers of HQLA securities. Our findings thus highlight that the LCR may promote the issuance of HQLA securities (typically public debt) compared to non-HQLA securities (typically private debt) and thus incentivizes the production of such assets. This in turn decreases again the HQLA premium as a second round effect. Ultimately, a non-zero HQLA premium implies a re-allocation of resources in the real economy (see, for example, Nyborg (2015)) which may be attributed to the change in regulatory requirements.[39]

Collateral frameworks: The price differentiation of HQLA and non-HQLA securities has implications for collateral frameworks of central banks too. On the one hand, if central banks accept both HQLA and non-HQLA securities in their collateral frameworks, banks may increasingly come to rely on central bank funding against non-HQLA securities (cheapest-to-deliver; see, for example, Nyborg (2016), Nyborg (2015), and Fecht et al. (2016)) if haircuts are not adjusted appropriately.[40] On the other hand, if central banks align their collateral policy and only accept HQLA collateral, they may reinforce the HQLA premium. The SNB is an example for a central bank that has responded to the LCR by aligning its collateral framework with the definition of HQLA. This trade-off also applies for interbank repo markets.

8 Conclusion

The Basel III LCR requires banks to hold an adequate stock of HQLA relative to their expected NCOF in order to withstand severe short-term liquidity shocks. In this paper we examine whether the HQLA classification of a security affects its market price. We quantify this change empirically and, as suggested by Stein (2013), call it HQLA premium.

In our empirical analysis, we show that there has been a yield differentiation between Level 1, Level 2 and non-HQLA securities before the regulatory change and we find that the LCR has reinforced this yield differentiation by adding an HQLA premium in the order of 4 bps. Guided by theoretical considerations, we claim that our estimate represents a lower bound of the HQLA premium. This is primarily due to ample supply of HQLA in the form of reserves resulting from

[39]Besides the HQLA premium there are other determinants which affect the incentives to produce specific assets (e.g. ratings). In this regard, the HQLA premium is an additional premium to the already existing determinants.

[40]Increasing central bank haircuts for non-HQLA securities may be one way to reduce this incentive. Moreover, the central bank could also impose quantitative limits for certain types of securities or limit the allotment volume in liquidity providing monetary policy operations.

the SNB's unconventional monetary policy measures and the fact that market interest rates are close to the interest rate paid on reserves.

The findings of this paper have various policy implications. First, in the event of a non-zero HQLA premium, several challenges arise for monetary policy implementation, as central banks may need to target a different level for their policy rate in order to take into account the HQLA premium and thus establish the same monetary conditions as before the regulatory change. Second, central banks may be forced to operate with larger balance sheets due to additional demand for reserves associated with banks' efforts to fulfill their LCR. This might also affect the choice of policy instruments central banks deploy to exit the current unconventional monetary policy. Third, in the event of a non-zero HQLA premium, issuing non-HQLA or Level 2 securities has become more expensive relative to Level 1 securities and thus incentivizes the production of Level 1 assets (primarily government debt). Fourth, central banks may need to adjust their collateral policy in response to the LCR in order to prevent banks from relying increasingly heavily on central bank funding against non-HQLA securities.

Our analysis is intended to contribute to a broader understanding of the LCR. Given the importance of the LCR for banks and the potentially far-reaching implications for the increasingly interconnected global financial system, further empirical research in this area is essential. Moreover, the methodology we have used to estimate the HQLA premium may also be applied to assess the HQLA premium in other currency areas.

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A Appendix

Figure 1: HQLA premium

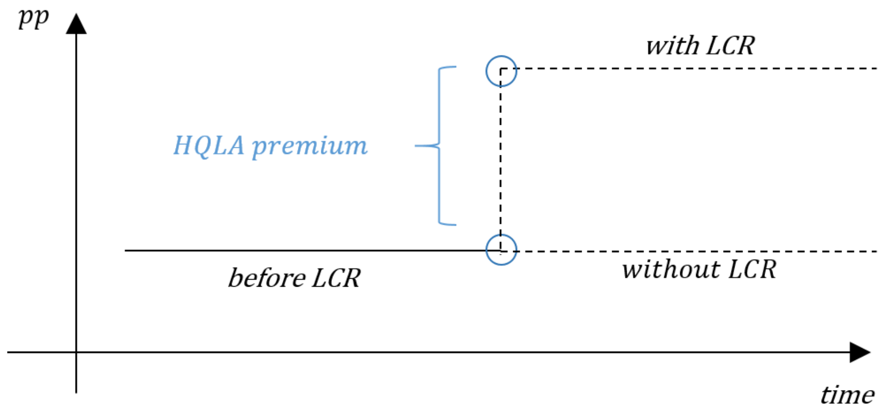


Figure 1 illustrates schematically the HQLA premium as an increase in the spread between Level 1 and non-HQLA securities caused by the LCR.

Figure 2: Equilibrium without LCR

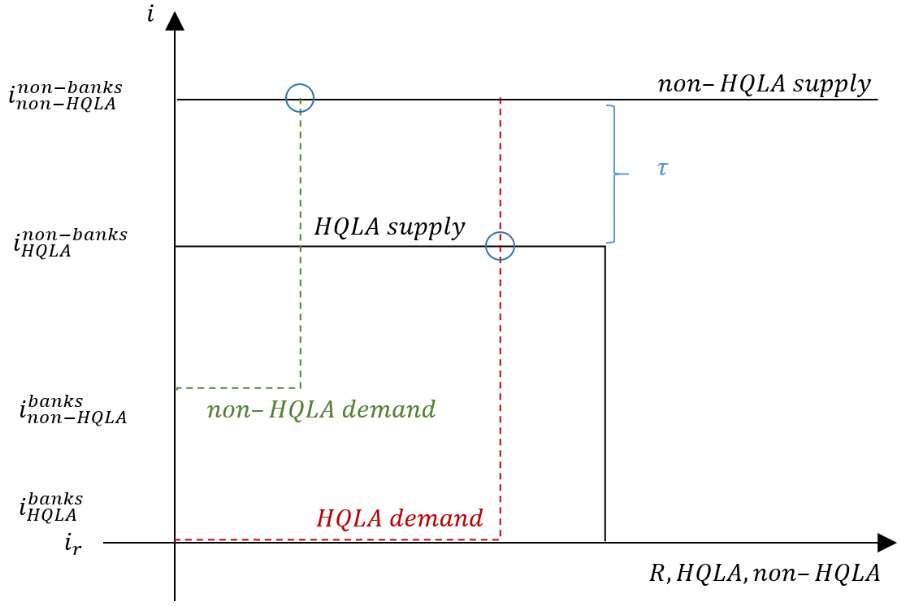


Figure 2 shows a possible equilibrium allocation without LCR. Quantities are depicted on the x-axis and yields on the y-axis. Solid lines represent supply curves and dotted lines demand curves. The price differentiation between HQLA and non-HQLA securities is reflected by the risk premium τ.

Figure 3: Equilibrium with LCR

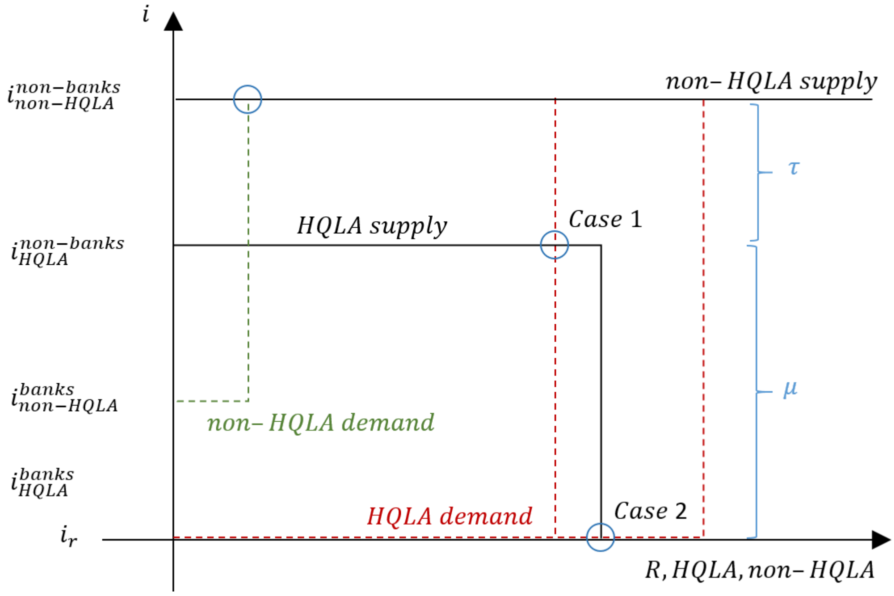


Figure 3 shows two possible equilibrium allocations with a binding LCR. Quantities are depicted on the x-axis and yields on the y-axis. Solid lines represent supply curves and dotted lines demand curves. In Case 1, the stock of HQLA securities is sufficiently large that banks can acquire additional HQLA securities without price impact and hence the price differentiation remains unchanged compared to the equilibrium without LCR. In Case 2, the demand for HQLA cannot be satisfied by the existing stock of HQLA. Hence the price for HQLA securities gets bid up (lower yield), thereby enforcing the existing price differentiation by introducing the HQLA premium μ.

Figure 4: Equilibrium with LCR and floor system of monetary policy

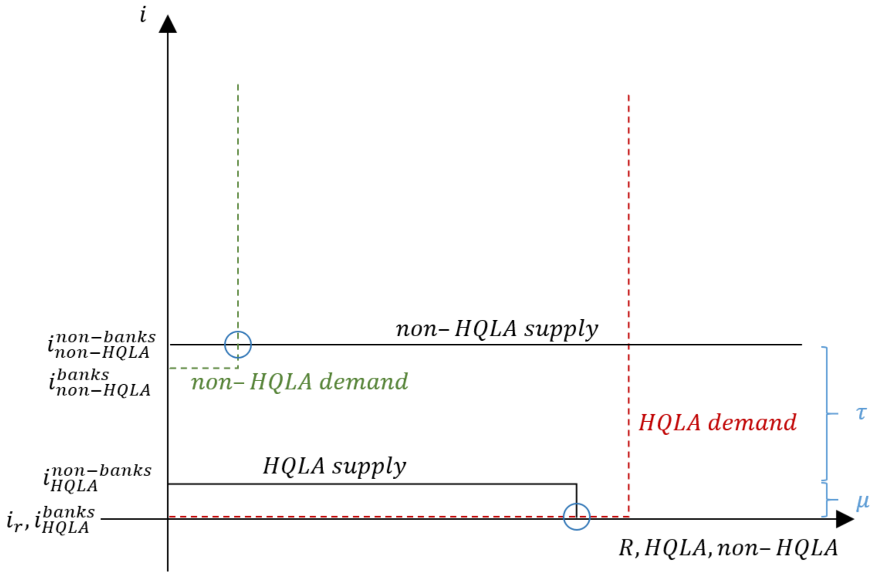


Figure 4 shows the equilibrium allocation with a binding LCR in an environment where the risk-free rate i_{HQLA} is close to the interest rate on reserves i_r. Quantities are depicted on the x-axis and yields on the y-axis. Solid lines represent supply curves and dotted lines demand curves. Although there is a shortage of HQLA securities, the HQLA premium μ is close to zero.

Figure 5: Credit ratings of securities denominated in CHF

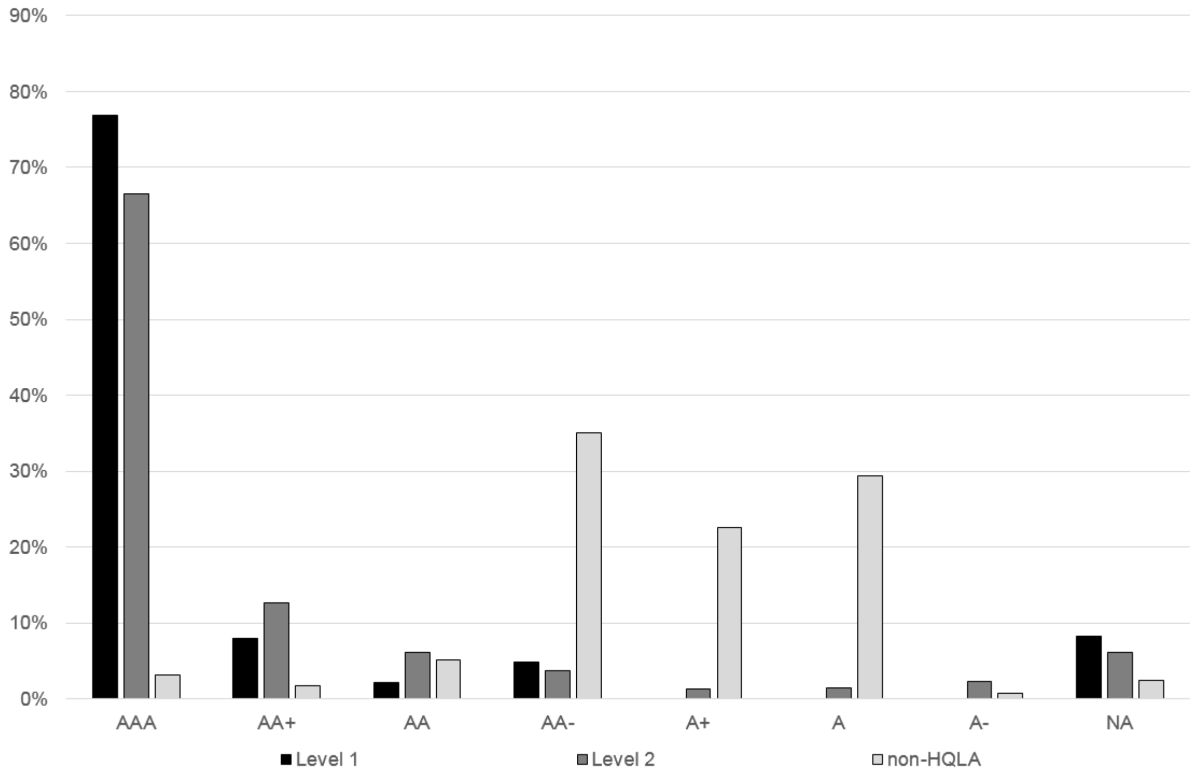


Figure 5 shows the volume-weighted share of securities by credit rating for Level 1, Level 2 and non-HQLA securities denominated in CHF. The black bars show Level 1 securities, the dark gray bars represent Level 2 securities, and the light gray bars show non-HQLA securities. The second-best rating from Moody's, S&P and Fitch as of 7 July 2014 is used for each security (note that if there is only one rating available, this rating is used).

Figure 6: Credit ratings of securities denominated in EUR

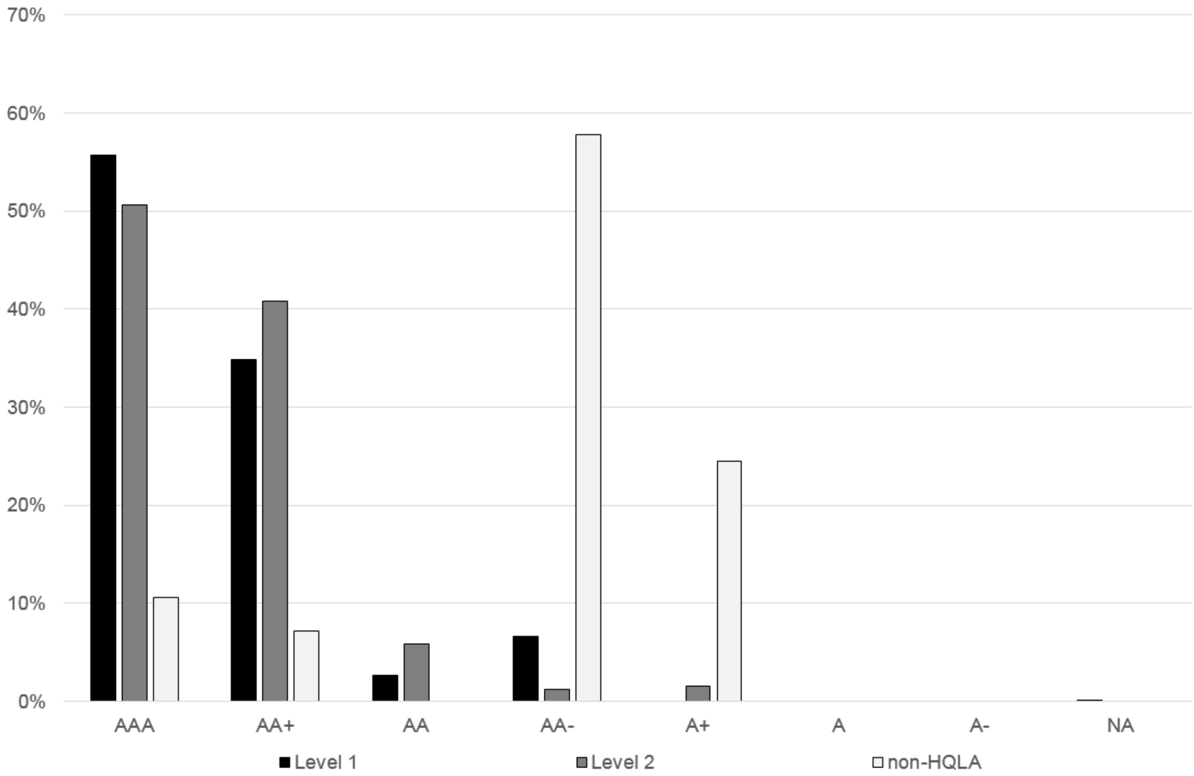


Figure 6 shows the volume-weighted share of securities by credit rating for Level 1, Level 2 and non-HQLA securities denominated in EUR. The black bars show Level 1 securities, the dark gray bars represent Level 2 securities, and the light gray bars show non-HQLA securities. The second-best rating from Moody's, S&P and Fitch as of 7 July 2014 is used for each security (note that if there is only one rating available, this rating is used).

Figure 7: Outstanding volume

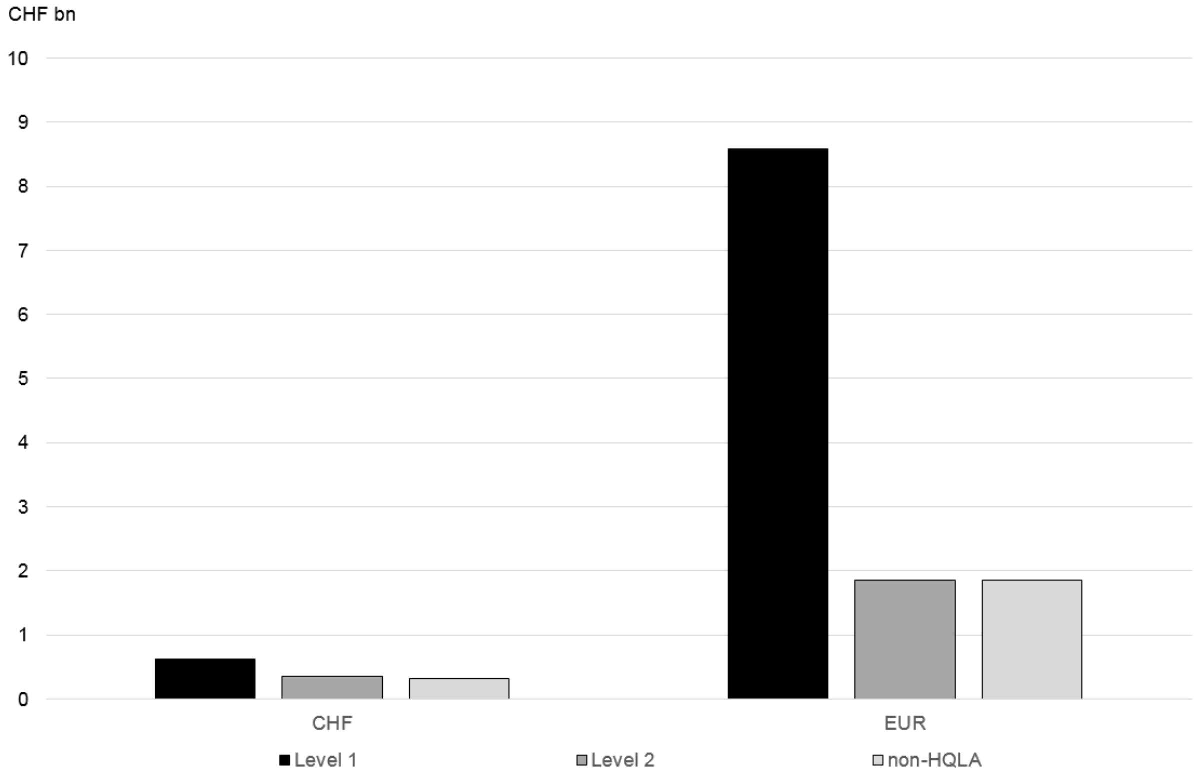
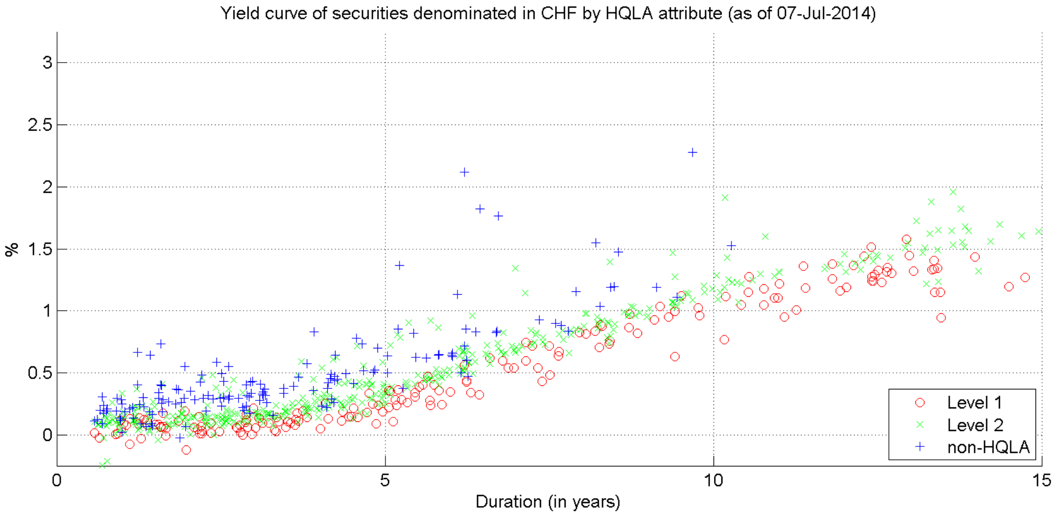


Figure 7 shows the average outstanding volume for Level 1, Level 2 and non-HQLA securities denominated in CHF (left bars) and EUR (right bars) as of 7 July 2014. Amounts are in billion CHF. The outstanding volume of EUR denominated bonds is converted to CHF using a EURCHF exchange rate of 1.0922 (8 March 2016). The black bars show the average outstanding volume of Level 1 securities, the dark gray bars represent the average outstanding volume for Level 2 securities, and the light gray bars show the average outstanding volume for non-HQLA securities.

Figure 8: Yield curves



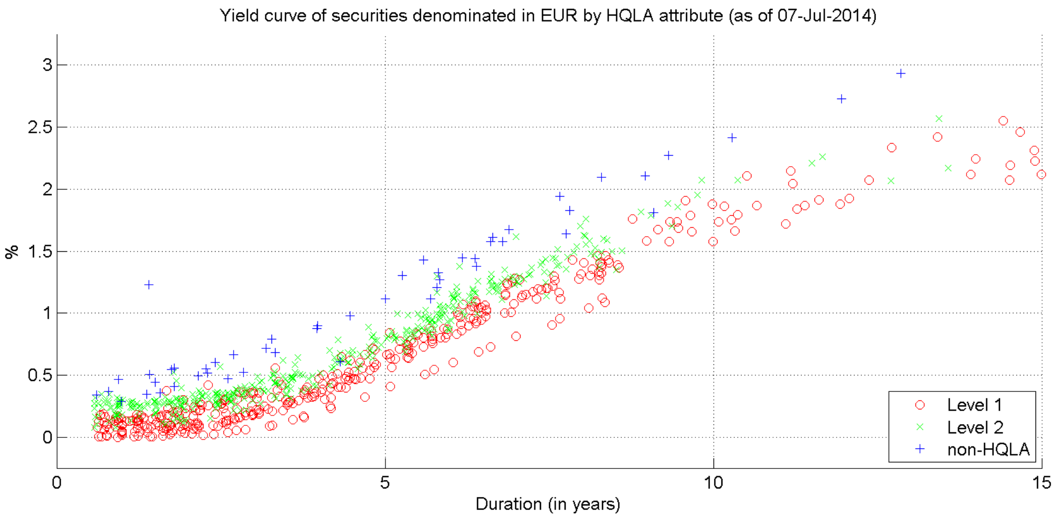


Figure 8 depicts the yield (y-axis) and the duration (in years; x-axis) for each security in our sample as of 7 July 2014 (note that the general shape of the yield curves is very similar, irrespective of the date considered). The red dots represent Level 1 securities, the green crosses Level 2 securities, and the blue "plus" signs non-HQLA securities. Securities denominated in CHF (EUR) are depicted in the upper (lower) part of the figure. Securities with a duration of more than 15 years are not depicted.

Figure 9: Yield development of securities denominated EUR

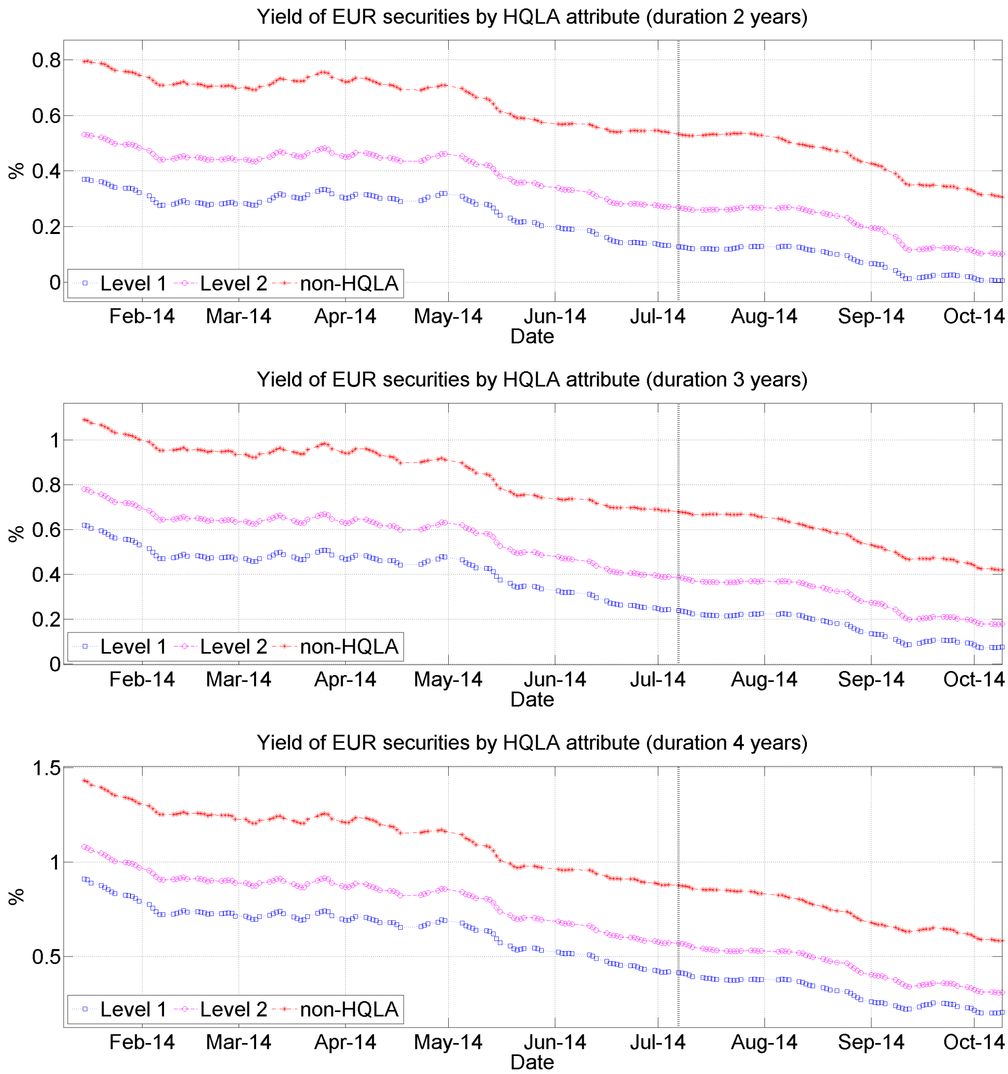


Figure 9 shows rolling one-week moving averages of generic yields with a constant duration of two, three and four years for securities denominated in EUR. Level 1 securities are represented by the blue squares, Level 2 securities by pink dots and non-HQLA securities by red crosses. The vertical lines represent the announcement days of the regulatory change in Switzerland (7 July 2014) and in the European Union (10 October 2014). Generic yields with a constant duration are calculated via the daily estimation of a yield curve for Level 1, Level 2 and non-HQLA securities in EUR using polynomic interpolation (with five degrees).

Figure 10: Yield development of securities denominated in CHF

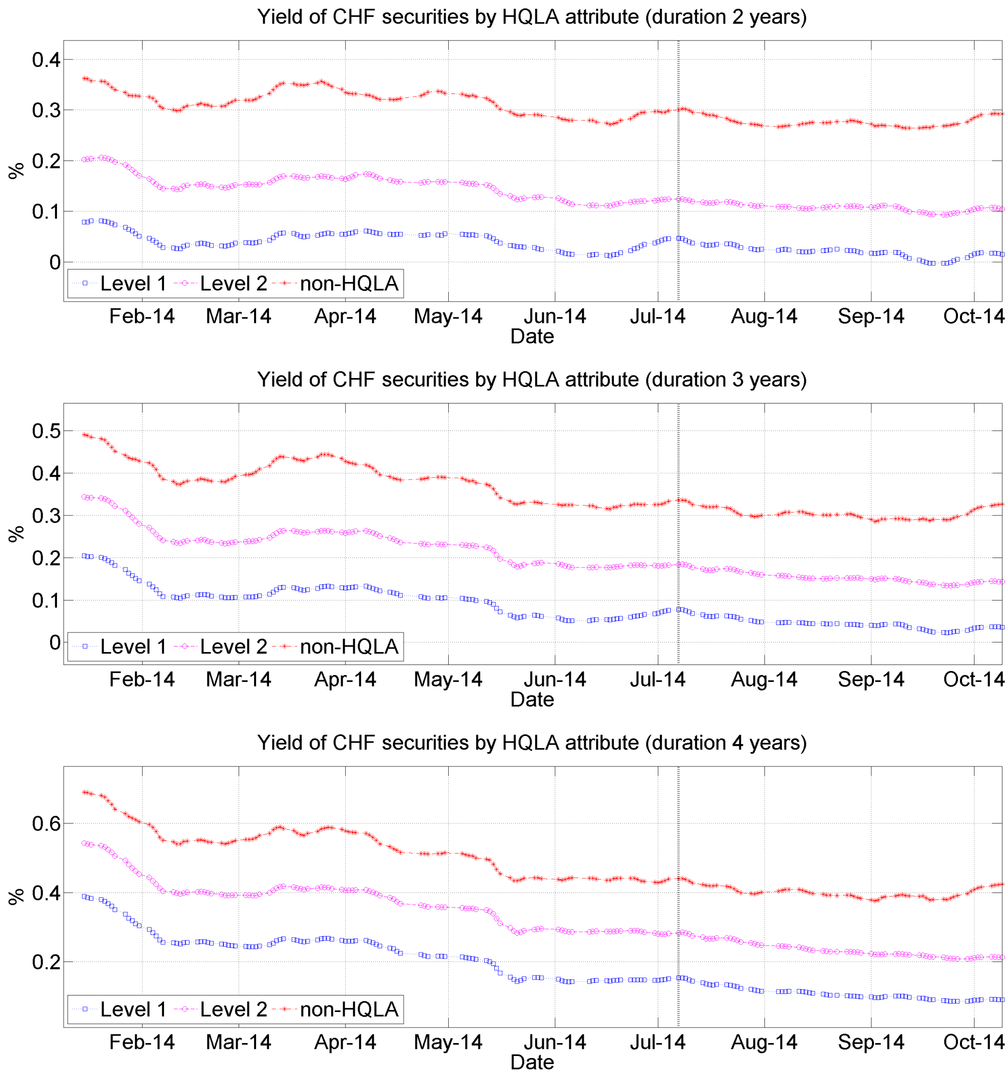


Figure 10 shows rolling one-week moving averages of generic yields with a constant duration of two, three and four years for securities denominated in CHF. Level 1 securities are represented by the blue squares, Level 2 securities by pink dots and non-HQLA securities by red crosses. The vertical lines represent the announcement days of the regulatory change in Switzerland (7 July 2014) and in the European Union (10 October 2014). Generic yields with a constant duration are calculated via the daily estimation of a yield curve for Level 1, Level 2 and non-HQLA securities in CHF using polynomic interpolation (with five degrees).

Figure 11: Timeline of key events

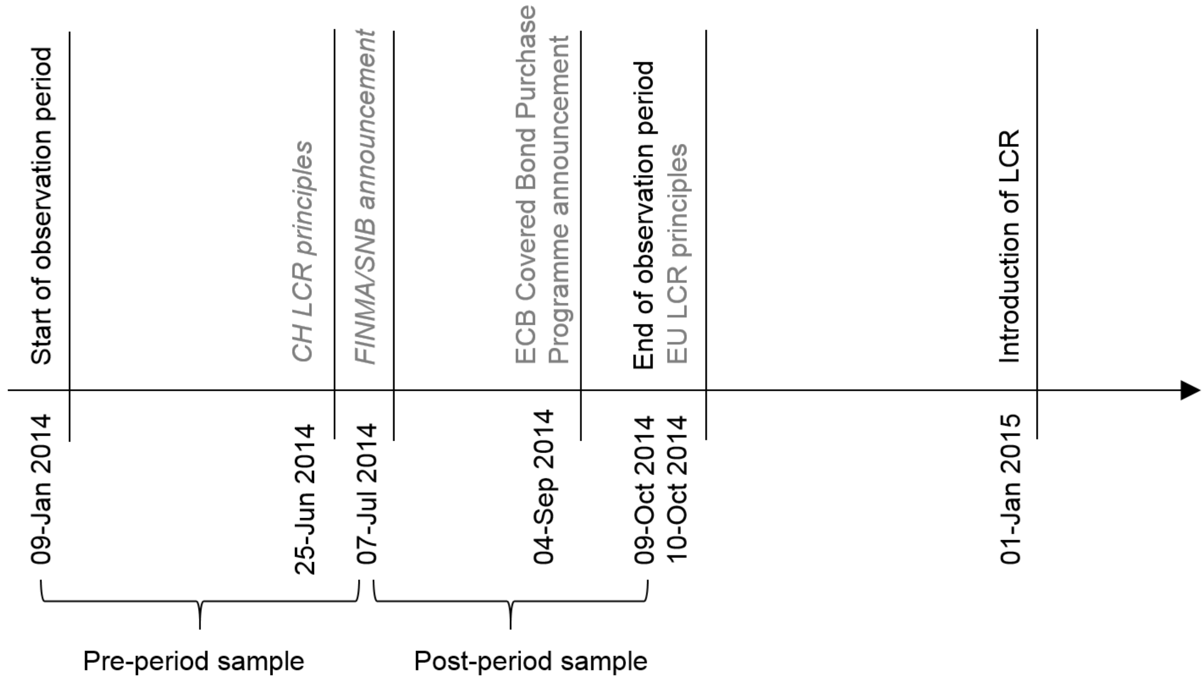


Figure 11 shows the timeline of key events. General events are depicted in black, Switzerland-specific events in gray and italics, and EU-specific events in gray and regular font. These events define the pre- and post-period samples of the empirical analysis.

Figure 12: Parallel trend assumption

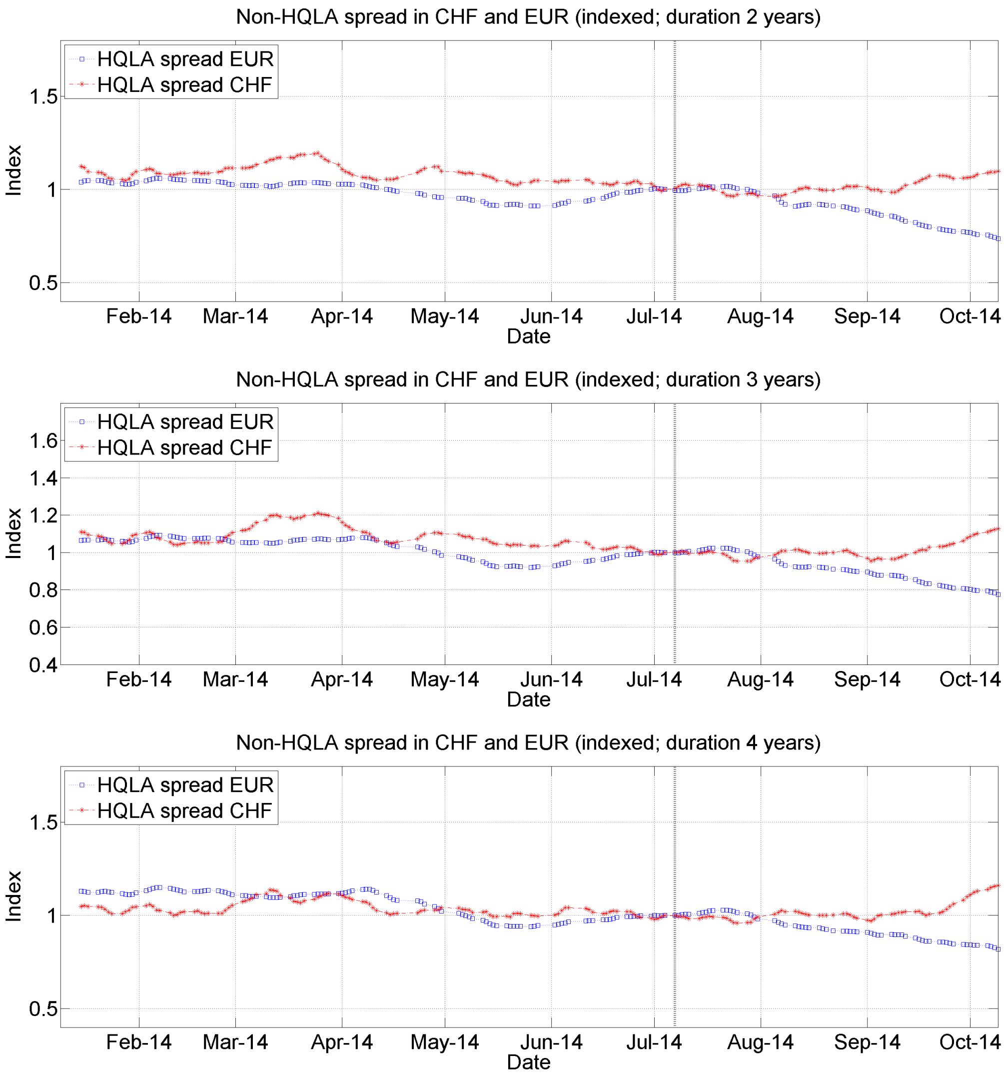


Figure 12 shows generic HQLA spreads (indexed rolling one-week moving averages) for securities denominated in EUR and CHF with a constant duration of two, three and four years. EUR HQLA spreads are calculated as non-HQLA$_{EUR}$-Level 1$_{EUR}$. CHF HQLA spreads are calculated as non-HQLA$_{CHF}$ - Level 1$_{CHF}$. The HQLA spread in EUR is represented by blue squares. The HQLA spread in CHF is depicted by red crosses. HQLA spreads are indexed to one on the day before the regulatory treatment (6 July 2014). The vertical lines represent the announcement days of the regulatory change in Switzerland (7 July 2014) and in the European Union (10 October 2014). Generic yields with a constant duration are calculated via the daily estimation of a yield curve for Level 1, Level 2 and non-HQLA securities denominated in EUR and CHF using polynomic interpolation (with five degrees).

Table 1: Descriptive statistics – number of securities

	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years	>10 years	**Total**
Panel A: Number of CHF securities												
Level 1	17	19	20	16	19	13	10	11	8	8	63	**204**
Level 2	57	48	49	49	39	38	27	21	19	19	62	**428**
non-HQLA	32	28	27	17	11	14	4	7	4	2	0	**146**
Total	**106**	**95**	**96**	**82**	**69**	**65**	**41**	**39**	**31**	**29**	**125**	**778**
Panel B: Number of EUR securities												
Level 1	57	65	53	40	38	37	28	27	9	11	46	**411**
Level 2	59	67	57	36	37	60	32	23	6	4	9	**390**
non-HQLA	8	8	6	3	2	7	4	3	2	1	3	**47**
Total	**124**	**140**	**116**	**79**	**77**	**104**	**64**	**53**	**17**	**16**	**58**	**848**
Panel C: Outstanding volume CHF (bn)												
Level 1	9	14	18	5	11	13	9	3	5	4	34	**125**
Level 2	23	17	19	18	14	14	11	7	6	6	18	**153**
non-HQLA	10	8	10	6	3	3	2	3	1	1	0	**47**
Total	**42**	**39**	**47**	**29**	**28**	**30**	**22**	**13**	**12**	**11**	**52**	**325**
Panel D: Outstanding volume EUR (bn)												
Level 1	409	391	364	359	241	262	230	254	60	102	458	**3130**
Level 2	90	105	101	68	66	102	50	38	11	10	16	**657**
non-HQLA	11	17	11	4	5	11	8	6	3	1	4	**81**
Total	**510**	**513**	**476**	**431**	**312**	**375**	**288**	**298**	**74**	**113**	**478**	**3868**

Table 1 shows the number of securities and the outstanding volume conditional on the currency of denomination, the duration (in years) and the HQLA attribute. Duration buckets between one and ten years are displayed. Securities are assigned to duration buckets according to their duration as of 7 July 2014. Duration buckets have a +/- 0.5-year range. For example, securities with a duration of 0.5 - 1.5 years are assigned to the 1-year duration bucket.

Table 2: Descriptive statistics maximum observed price decline within 30 days (in %)

	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years
Panel A: CHF securities										
Level 1	-0.36	-0.42	-0.57	-0.50	-0.48	-0.58	-0.59	-1.01	-0.93	-0.88
Level 2	-0.42	-0.44	-0.54	-0.52	-0.56	-0.53	-0.61	-0.90	-0.86	-0.91
non-HQLA	-0.42	-0.60	-0.67	-0.72	-0.81	-0.86	-1.15	-0.90	-1.10	-2.23
Panel B: EUR securities										
Level 1	-0.28	-0.39	-0.44	-0.54	-0.64	-0.77	-1.02	-1.28	-1.79	-2.20
Level 2	-0.31	-0.39	-0.42	-0.51	-0.63	-0.71	-0.88	-1.27	-1.70	-2.50
non-HQLA	-0.40	-0.44	-0.47	-0.62	-0.64	-0.82	-0.83	-1.09	-1.43	-1.05

Table 2 shows the maximum observed price decline within 30 days (in % of the securities' value) for securities denominated in CHF and EUR conditional on the HQLA attribute and the duration (simple averages per category). The observation period runs from 9 January to 17 December 2014. Duration buckets between one and ten years are displayed. Securities are assigned to duration buckets according to their duration as of 7 July 2014. Duration buckets have a +/- 0.5-year range. For example, securities with a duration of 0.5 - 1.5 years are assigned to the 1-year duration bucket.

Table 3: Descriptive statistics – standard deviation of daily price changes (in percentage points)

	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years
Panel A: CHF securities										
Level 1	0.03	0.04	0.06	0.06	0.08	0.10	0.12	0.16	0.17	0.16
Level 2	0.03	0.05	0.06	0.07	0.10	0.09	0.11	0.18	0.16	0.15
non-HQLA	0.04	0.07	0.08	0.12	0.15	0.14	0.16	0.18	0.20	0.31
Panel B: EUR securities										
Level 1	0.01	0.03	0.05	0.09	0.12	0.16	0.19	0.23	0.26	0.29
Level 2	0.02	0.03	0.05	0.08	0.12	0.15	0.18	0.22	0.26	0.31
non-HQLA	0.03	0.03	0.05	0.09	0.11	0.15	0.17	0.20	0.25	0.25

Table 3 shows the standard deviation of daily price changes (in % of the securities' value) for securities denominated in CHF and EUR conditional on the HQLA attribute and the duration (simple averages per category). The observation period runs from 9 January to 17 December 2014. Duration buckets between one and ten years are displayed. Securities are assigned to duration buckets according to their duration as of 7 July 2014. Duration buckets have a +/- 0.5-year range. For example, securities with a duration of 0.5 - 1.5 years are assigned to the 1-year duration bucket.

Table 4: Descriptive statistics – yields

	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years	>10 years
Panel A: Yields of CHF securities (in percent), pre-period sample											
Level 1	-0.00	-0.03	0.07	0.30	0.32	0.49	0.74	1.04	1.08	1.23	1.47
Level 2	0.15	0.17	0.22	0.42	0.62	0.78	0.98	1.14	1.31	1.48	1.74
non-HQLA	0.24	0.33	0.38	0.54	0.88	1.00	1.22	1.23	1.49	2.31	NaN
Panel B: Yields of CHF securities (in percent), post-period sample											
Level 1	0.03	0.01	0.03	0.11	0.15	0.25	0.40	0.65	0.67	0.84	1.15
Level 2	0.12	0.11	0.14	0.23	0.35	0.47	0.64	0.76	0.91	1.10	1.40
non-HQLA	0.20	0.29	0.30	0.35	0.59	0.71	0.89	0.88	1.13	1.81	NaN
Panel C: Yields of EUR securities (in percent), pre-period sample											
Level 1	0.17	0.25	0.42	0.68	0.97	1.22	1.52	1.64	2.12	2.22	2.62
Level 2	0.35	0.46	0.65	0.88	1.19	1.46	1.74	1.96	2.08	2.42	2.74
non-HQLA	0.58	0.75	0.97	1.18	1.58	1.79	2.11	2.41	2.61	2.80	3.25
Panel D: Yields of EUR securities (in percent), post-period sample											
Level 1	0.05	0.07	0.13	0.27	0.48	0.68	0.93	1.07	1.50	1.63	2.08
Level 2	0.22	0.25	0.32	0.45	0.66	0.89	1.14	1.34	1.43	1.78	2.15
non-HQLA	0.42	0.50	0.62	0.74	0.99	1.20	1.49	1.87	1.99	2.29	2.71

Table 4 shows the volume-weighted average yields conditional on the currency of denomination, the HQLA attribute, and the duration bucket in the pre- and post-period. The observation period runs from 9 January to 9 October 2014. Duration buckets between one and ten years are displayed. Securities are assigned to duration buckets according to their duration as of 7 July 2014. Duration buckets have a +/- 0.5-year range. For example, securities with a duration of 0.5 - 1.5 years are assigned to the 1-year duration bucket.

Table 5: Dummy variables in regression analysis

	Level 1		non-HQLA	
Dummy variables	EUR	CHF	EUR	CHF
non-HQLA			1	1
CHF		1		1
CHF x non-HQLA				1
const.	1	1	1	1

Table 5 exemplifies the use of dummy variables (rows) in the regression specification, given the securities' HQLA attributes as well as the currency of denomination (columns).

Table 6: Difference-in-difference regression results (coefficient are in percentage points)

	(1) Baseline	(2) Liquidity	(3) CH-issuer	(4) LiqV	(5) Placebo	(6) Level 2
CHF x non-HQLA	0.0387**	0.0436***	0.0446**	0.0342**	0.00527	0.0130
	(2.53)	(2.83)	(2.53)	(2.22)	(0.66)	(0.90)
non-HQLA	-0.0576***	-0.0576***	-0.0576***	-0.0559***	0.00372	-0.0338***
	(-4.52)	(-4.51)	(-4.51)	(-4.38)	(0.95)	(-2.92)
CHF	0.150***	0.155***	0.183***	0.159***	0.0167*	0.0902***
	(9.31)	(9.86)	(7.51)	(9.71)	(1.84)	(8.18)
CHF x Level 2						0.0167**
						(2.07)
Level 2						-0.0307***
						(-7.19)
Constant	-0.0678***	-0.0678***	-0.0678***	-0.0739***	-0.0444***	-0.0220***
	(-5.89)	(-5.88)	(-5.87)	(-6.29)	(-11.14)	(-3.27)
Observations	822	735	589	822	822	1660
Adjusted R^2	0.857	0.884	0.858	0.852	0.471	0.863
Duration (CHF/EUR)	Yes	Yes	Yes	Yes	Yes	Yes
Duration^2 (CHF/EUR)	Yes	Yes	Yes	Yes	Yes	Yes

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6 shows the baseline regression results (Column (1)) and the robustness checks (Columns (2) - (6)) for the difference-in-difference analysis. Coefficients are expressed in percentage points. The dependent variable is the absolute yield change between the average yield post and pre $((\bar{y}^{\text{Post}} - \bar{y}^{\text{Pre}})_i)$ the regulatory change (7 July 2014) for each individual security (i). The regression specification is given in Equation (3). The pre-period sample runs from 9 January to 6 July 2014. The post-period sample lasts from 7 July to 9 October 2014. Column (2) shows the regression results when using only securities with an outstanding volume of at least CHF 175 mn. Column (3) shows the regression results when omitting CHF securities issued by foreign issuers. Column (4) shows the regression results when using the publication of the legislative principles as the regulatory change. Column (5) shows the results of the placebo regression when using a fictional regulatory change during the pre-period sample (between 9 January and 6 March 2014, fictional regulatory change 5 February 2014). Column (6) shows the regression results using a post-period sample which runs only until one day before the announcement of the ECB covered bond purchase program (announced on 4 September 2014) using Level 1, Level 2 and non-HQLA securities. Regression coefficients for the securities' duration are not displayed (see Table 7 for more details). Huber-White corrected standard errors are used. ***, ** and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively. t-statistics are in parentheses below the coefficients.

Table 7: Alternative econometric specification – term structure (coefficients are in percentage points)

	(1) Baseline	(2) Check I	(3) Check II	(4) Check III	(5) Check IV	(6) Check V
CHF x non-HQLA	0.0387**	0.0421**	0.0421**	0.0401***	0.0396**	0.0412***
	(2.53)	(2.32)	(2.26)	(2.63)	(2.56)	(3.00)
non-HQLA	-0.0576***	-0.0615***	-0.0608***	-0.0586***	-0.0582***	-0.0569***
	(-4.52)	(-3.85)	(-3.71)	(-4.61)	(-4.51)	(-5.33)
CHF	0.150***	0.219***	0.193***	0.142***	0.160***	0.0857***
	(9.31)	(10.22)	(6.95)	(8.46)	(10.23)	(5.47)
Duration (EUR)	-0.101***			-0.105***	-0.0962***	-0.161***
	(-21.16)			(-21.49)	(-18.67)	(-42.62)
Duration (CHF)	-0.0795***			-0.0812***	-0.0772***	-0.101***
	(-21.07)			(-21.15)	(-21.32)	(-15.11)
Duration^2(EUR)	0.00382***			0.00401***	0.00360***	0.0114***
	(12.13)			(12.43)	(10.50)	(25.47)
Duration^2(CHF)	0.00311***			0.00316***	0.00306***	0.00580***
	(13.45)			(13.63)	(13.45)	(6.65)
Maturity (CHF)		-0.0600***	-0.0591***			
		(-12.89)	(-12.55)			
Maturity (EUR)		-0.0556***	-0.0555***			
		(-11.46)	(-11.30)			
Maturity^2(CHF)		0.00186***	0.00183***			
		(8.00)	(7.83)			
Maturity^2(EUR)		0.00126***	0.00126***			
		(6.14)	(6.10)			
Coupon EUR			-0.000711			
			(-0.21)			
Coupon CHF			0.00953			
			(1.53)			
Duration^3(EUR)						-0.000242***
						(-16.88)
Duration^3(CHF)						-0.0000845***
						(-2.83)
Constant	-0.0678***	-0.176***	-0.175***	-0.0466***	-0.0986***	0.0314***
	(-5.89)	(-11.28)	(-10.47)	(-3.86)	(-8.45)	(4.25)
Observations	822	822	822	822	822	822
Adjusted R^2	0.857	0.768	0.768	0.860	0.853	0.889
Duration/Maturity as of:	7 Jul 14	7 Jul 14	7 Jul 14	9 May 14	10 Oct 14	7 Jul 14

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7 shows our baseline regression results (Column (1)) as well as applied robustness tests for possible term structure specifications (Column (2 - 6)). Column (2) shows the regression results when using the securities' residual maturity instead of the duration to control for the term structure of interest rates, whereas in Column (3), we additionally control for the securities' coupon. Column (4) and (5) display the regression results when using the duration of securities as of 9 May and 10 October respectively instead of 7 July 2014. Finally, Column (6) reports the regression results when including an additional cubic term to control for the term structure of interest rates into our baseline regression model. The dependent variable is the absolute yield change between the average yield post and pre ($(\bar{y}^{\text{Post}} - \bar{y}^{\text{Pre}})_i$) the regulatory change (7 July 2014) for each individual security (i). The regression specification is given in Equation (3). The pre-period sample runs from 9 January to 6 July 2014. The post-period sample lasts from 7 July to 9 October 2014. Huber-White corrected standard errors are used. ***, ** and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively. t-statistics are in parentheses below the coefficients.

Table 8: Dummy variables in regression analysis

	Level 1		Level 2		non-HQLA	
Dummy variables	EUR	CHF	EUR	CHF	EUR	CHF
Level 2			1	1		
non-HQLA					1	1
CHF		1		1		1
CHF x Level 2				1		
CHF x non-HQLA						1
const.	1	1	1	1	1	1

Table 8 exemplifies the use of dummy variables (rows) in the regression specification including Level 2 securities, given the securities' HQLA attributes as well as the currency of denomination (columns).

Table 9: Alternative econometric specification – HQLA spreads (coefficients are in percentage points)

	(1) HQLA spreads	(2) HQLA spreads
CHF x Post	0.0612***	0.0612***
	(22.80)	(12.21)
Post	-0.0413***	-0.0413***
	(-20.40)	(-10.89)
CHF	-0.141***	-0.141***
	(-89.93)	(-48.30)
Constant	0.325***	0.325***
	(128.48)	(68.81)
Observations	3680	3680
Adjusted R^2	0.906	0.906
Duration FE	Yes	Yes
SE	Robust	Newey-West (4)

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 9 shows the regression results of a difference-in-difference analysis of HQLA spreads denominated in CHF and EUR with generic duration of one to ten years (as illustrated in Figure 12). Coefficients are in percentage points. The dependent variable is the yield spread between non-HQLA and Level 1 securities denominated in CHF and EUR with a generic duration j. Both regression specifications contain duration fixed effects dummy variables. The regression specification is given in Equation (4). The pre-period sample runs from 9 January to 6 July 2014. The post-period sample lasts from 7 July to 9 October 2014. ***, ** and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively. Column (1) reports Huber-White corrected standard errors and Column (2) Newey-West standard errors. For Newey-West standard errors, the number of lags is set more conservative than suggested by Greene (2003) to the rounded up integer to the fourth root of the number of time series observations (indicated by the number in brackets).

Table 10: Alternative econometric specification – CHF HQLA spreads (coefficients are in percentage points)

	(1) HQLA spreads	(2) HQLA spreads
Post	0.0198***	0.0201***
	(8.56)	(8.82)
VIX		0.000893*
		(1.83)
Constant	0.154***	0.142***
	(33.56)	(18.16)
Observations	1840	1840
Adjusted R^2	0.958	0.958
Duration FE	Yes	Yes
SE	Newey-West (4)	Newey-West (4)

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10 shows the regression results when using HQLA spreads denominated in CHF with duration of one to ten years (as illustrated in Figure 10), only. Column (1) shows the results when regressing the HQLA spreads on a post-period sample dummy. In Column (2), we additionally show the results when including the CBOE Volatility Index (VIX) as a control variable. Both regression specifications contain duration fixed effects dummy variables. The regression specification is as follows: $\text{spread}_{j,t} = \alpha_j + \beta_1 \text{Post}_{j,t} + \beta_2 \text{VIX}_{j,t} + \epsilon_{j,t}$, where the control variable (VIX) is only included in the regression specification of Column (2). The pre-period sample runs from 9 January to 6 July 2014. The post-period sample lasts from 7 July to 9 October 2014. ***, ** and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively. Newey-West standard errors are reported. For Newey-West standard errors, the number of lags is set more conservative than suggested by Greene (2003) to the rounded up integer to the fourth root of the number of time series observations (indicated by the number in brackets). Coefficients are in percentage points.

Appendix III

Acknowledgements

I am very grateful to my thesis supervisor Kjell Nyborg who gave me the opportunity to complete a dissertation under his guidance and for supporting me with helpful advice and comments. I am further indebted to Sébastien Kraenzlin and Matthias Jüttner for their constant support and for making the dissertation project possible. Moreover, I am very grateful to my co-authors Basil Guggenheim, Benjamin Müller, Silvio Schumacher, and Luzian Steiner for the interesting and productive teamwork. I would also like to express my gratitude to the Swiss National Bank and in particular to Dewet Moser and Karl Hug for giving me the unique opportunity to complete a dissertation while working in the Money Market Unit at the Swiss National Bank. Finally, I thank my family and Charlotte for their everlasting support.

Appendix IV

Curriculum Vitae

Lucas Marc Fuhrer was born on 5 December 1984 in Bern. He is a citizen of the city of Zurich and his place of origin is Trubschachen (Bern). His parents are Bruno and Kathrin Fuhrer, both living in Unterramsern. Lucas holds a Master's degree in Economics from the University of Bern. He joined the Swiss National Bank in 2011 in the Money Market and Foreign Exchange Division. Currently, he works as a senior economist in the Swiss National Bank's money market analysis team.